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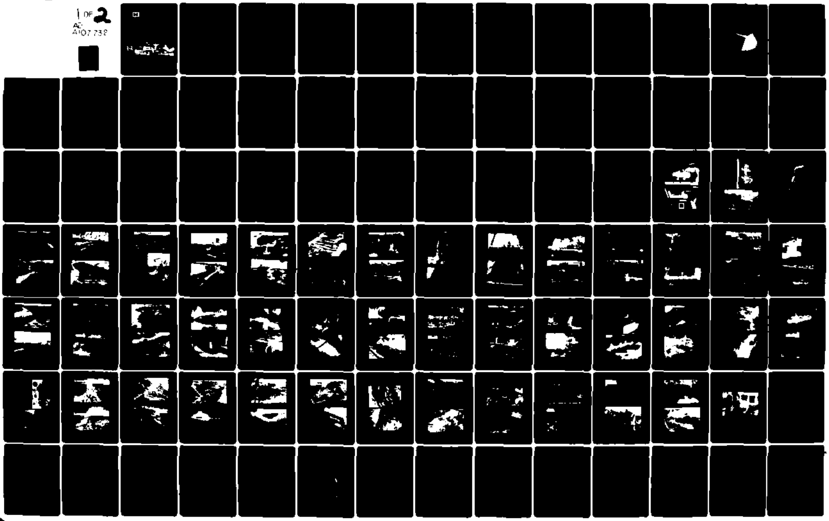

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MISCELLANEOUS PAPER GL-81-4

EVALUATION OF MEMBRANE-TYPE MATERIALS FOR STREAMBANK EROSION PROTECTION

by

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August 1981
Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Work Unit 4, Section 32
Streambank Erosion Control, Evaluation and Demonstration
Act of 1974 (PL 93-251)

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER Miscellaneous Paper GL-81-4	2. GOVT ACCESSION NO. AD A107 772
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) EVALUATION OF MEMBRANE-TYPE MATERIALS FOR STREAMBANK EROSION PROTECTION	5. TYPE OF REPORT & PERIOD COVERED Final report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Dewey W. White, Jr.	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Geotechnical Laboratory P. O. Box 631, Vicksburg, Miss. 39180	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Work Unit 4, Section 32 Program
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314	12. REPORT DATE August 1981
	13. NUMBER OF PAGES 113
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Bank protection
Erosion control
Laboratory tests
Membranes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this study was to investigate new materials and construction techniques for streambank protection by preventing erosion of the banks. The specific materials used were: T15, laminated vinyl-coated nylon; T16, neoprene-coated nylon; Hypalon, synthetic rubber-coated 5×5 and 10×10 polyester scrim membranes, and Bidim C-34 and C-38, spunbonded, continuous polyester filament filter fabrics.

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20. ABSTRACT (Continued).

Laboratory tests were conducted to determine physical characteristics, such as grab, trapezoidal tear, joint-breaking (as applicable) strength, and elongation of the materials used in the investigation.

The primary field test site selected for this study was along the banks of the Big Black River just south of Vicksburg, Mississippi. However, before the materials could be installed at this site, a permit was required from the Corps of Engineers, Vicksburg District. Therefore, an alternate test site was selected at Durden Creek located on the U. S. Army Engineer Waterways Experiment Station facility. There were two main purposes for selecting the alternate site. One was to verify experimental installation techniques, and the other was to collect limited data on the performance of the materials when used for erosion control purposes in the event the permit to conduct the tests on the Big Black River was denied.

Various construction techniques were used to install the membrane materials at both field test sites. These techniques included: (a) a stepped membrane encapsulated soil layer (MESL), (b) the "blanket" where the membranes were draped over the slope of the banks and anchored along the edges in ditches, and (c) MESL items. Riprap placed over the filter fabrics was used as the standard for comparing the performance of all test materials.

As a result of tests, data collected, and observations made on Durden Creek and the Big Black River, all membrane materials used performed satisfactorily in protecting streambanks and riverbanks from erosion during normal streamflows as long as the banks remain stable. It is doubtful whether any known methods of construction and materials will prevent erosion after the banks fail.

Based on field test results, it is recommended that (a) membranes should be used to prevent erosion when installed as blankets, stepped MESL, or MESL sections, and (b) the type of installation method should be determined by the condition of the bank where protection is provided. Field performance and material costs indicate the cost effectiveness of membrane materials installed as temporary protection of streambanks.

PREFACE

The Streambank Erosion Control, Evaluation, and Demonstration Act of 1974 Public Law 93-251, Section 32 (as amended by Public Law 94-587, Sections 155 and 161) authorized the Secretary of the Army, acting through the Chief of Engineers, to establish and conduct a national streambank erosion prevention and demonstration program. The study reported herein was conducted under Work Unit 4, Research on Soil Stability and Identification of Causes of Streambank Erosion, Task III, Geotechnical Research for New Methods and Techniques for Bank Protection.

The tests pertinent to this investigation were performed at the U. S. Army Engineer Waterways Experiment Station (WES) and at the Big Black River Test Site near WES during June 1979 through December 1980 under the general supervision of Mr. James P. Sale (retired) Chief; Mr. Ronald L. Hutchinson (retired) Acting Chief; Mr. Clifford L. McAnear, Acting Chief; Dr. Don C. Banks, Acting Chief; Mr. Richard G. Ahlvin (retired) Assistant Chief; and Dr. Paul F. Hadala, Assistant Chief of the Geotechnical Laboratory (GL). Personnel of the Pavement Systems Division, GL, actively engaged in the planning, testing, analyzing, and reporting phases of the investigation were Messrs. Sidney G. Tucker, Dewey W. White, Jr., Alston C. Spivey, Jr., and Dave Ellison.

The Engineering and Construction Services Division had the responsibility of construction and installation of the test sections under the supervision of Messrs. Angelo Del Priore (retired), Thomas P. Williams, and Wadell S. Turner. Personnel of the Hydraulics Laboratory who collected data on stream cross sections, depths, velocities, and discharges were Messrs. Dale Hart, John Hite, James E. Hall, and Timothy L. Fagerburg. This report was prepared by Mr. Dewey W. White, Jr.

Commanders and Directors of the WES during the conduct of this study and preparation of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. Fred R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres
ounces (mass)	28.34952	grams
ounces per square yard	33.90575	grams per square metre
pounds (force)	4.448222	newtons
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square metres
tons (2000 lb, mass)	907.1847	kilograms

EVALUATION OF MEMBRANE-TYPE MATERIALS FOR STREAMBANK EROSION PROTECTION

PART I: INTRODUCTION

Background

1. The Steambank Erosion Control and Demonstration Act of 1974 (Public Law 93-251, Section 32, as amended by Public Law 94-587, Sections 155 and 161) authorized the Secretary of the Army, acting through the Chief of Engineers, to establish and conduct a National Streambank Erosion Prevention and Demonstration Program. The legislatively specified objectives of the "Section 32 Program" consist of: (a) an evaluation of the extent of streambank erosion on navigable rivers and their tributaries; (b) development of new methods and techniques for bank protection, research on soil stability, and identification of the causes of erosion; (c) a report to the Congress on the results of such studies with the recommendations of the Secretary of the Army on means for the prevention and correction of streambank erosion; and (d) demonstration projects, including bank protection works. The study described herein was conducted as Task III of Work Unit 4, Geotechnical Research for New Methods and Techniques for Bank Protection.

Objectives

2. The objectives of this study were to investigate new materials and construction techniques for streambank protection by preventing erosion to upper and lower banks. Specifically, the selection of materials and the use of construction techniques and methods were made primarily for private landowners with limited resources available other than light equipment and hand labor. Those combinations of materials and techniques that showed promise of providing cost-effective temporary protection using hand-labor methods were considered to be the most

desirable. The materials recommended as a result of previous channel model tests for further investigation and field testing were also used in this study.*

Scope

3. This report describes the investigation of various membrane materials, filters, and construction techniques that may be adapted for streambank protection by controlling upper and lower bank erosion. The materials investigated were used for applications to protect upper and lower banks on Durden Creek. However, on the Big Black River these materials were used to protect only the upper banks because the weather conditions and high river stages that occurred during construction of test items prevented their use on lower banks.

Problem

4. Streambank erosion, i.e., lateral or side cutting, occurs along stretches of streams and rivers exhibiting rather diverse geological and geomorphological characteristics throughout the United States. The American Society of Civil Engineers Task Committee on Channel Stabilization Works has identified six types of bank erosion failures:

a. Current attack at toe of underwater slope during falling stream stage.

b. Current scour on bank sides.

c. Sluffing of saturated cohesive banks caused by rapid drawdown.

d. Liquefaction of saturated silty and sandy bank material.

e. Erosion by seepage out from banks at low channel velocities.

f. Wave scour of upper bank caused by wind or passing vessels.

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* C. R. Styron III. 1979. "Section 32 Program, Streambank Erosion Control, Evaluation and Demonstration, Work Unit 4- Research on Soil Stability and Identification of Causes of Streambank Erosion; Investigation Report 2, Evaluation of Rigid and Flexible Materials for Bank Protection," U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

5. Of these six types of failure, four (a, c, d, and e) are caused by short-term (probably seasonal) changes in fluvial process and occur after flood (falling stages). The other two types (b and f) are not directly related to short-term changes, although it would seem reasonable for current scour (b) to be more effective during high-water stages. It is apparent that climate and stage fluctuation are of considerable importance in determining the erosion susceptibility of meandering and possibly youthful streams.

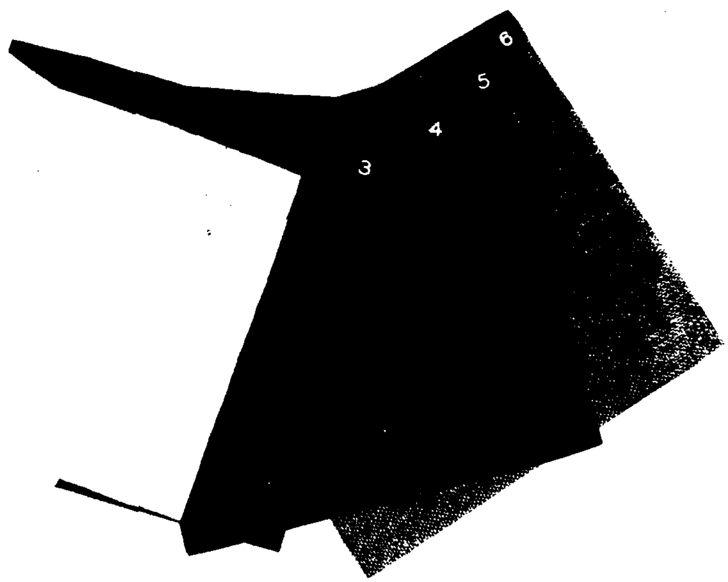
6. The list of failure types suggests that four (a, c, d, and e) are caused more directly by slope instability initiated by scour. Failures such as these may be more dependent upon bank material properties than failures caused by scour alone. Therefore, the need exists to determine if these failures can be controlled or eliminated by using membrane-type materials.

PART II: MATERIAL DESCRIPTION

7. The membranes used for tests in this investigation included T15 and T16. These materials were previously tested* in a channel model, and as a result of these tests, the recommendation was made that these membranes be field tested. In addition to these membranes, two experimental membranes and two filter fabrics were selected for testing and comparison purposes. The membranes, filter fabrics, and other materials used in this investigation are described below and listed in Table 1.

<u>a</u>. Membranes:

(1) T15: laminated vinyl-coated nylon; color, green; weight, 19.1 oz/yd^2**; thickness, 0.0261 in.; sheet size, 50 by 50 ft (Figure 1, No. 6).



1 BIDIM C 38
2 BIDIM C 34
3 HYPALON 5X5
4 HYPALON 10X10
5 T16
6 T15

Figure 1. Membranes and filter fabrics

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* Styron op. cit.
** A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

(2) T16: neoprene-coated nylon; color, black; weight, 16.0 oz/yd^2; thickness, 0.0194 in.; sheet size, 50 by 50 ft (Figure 1, No. 5).

(3) Hypalon 5×5: synthetic rubber-coated 5×5 polyester scrim; color, black; weight, 33.4 oz/yd^2; thickness, 0.0370 in.; sheet size, 50 by 50 ft (Figure 1, No. 3).

(4) Hypalon 10×10: synthetic rubber-coated 10×10 polyester scrim; color, black; weight, 31.0 oz/yd^2; thickness, 0.0340 in.; sheet size, 50 by 50 ft (Figure 1, No. 4).

b. Filter fabrics:

(1) Bidim C-34: spunbounded, continuous polyester filaments; color, grey; weight, 7.7 oz/yd^2; thickness, 0.081 in.; roll size, 13 ft 10 in. wide by 984 ft long (Figure 1, No. 2).

(2) Bidim C-38: spunbonded, continuous polyester filaments; color, grey; weight, 8.1 oz/yd^2; thickness, 0.093 in.; roll size, 17 ft 5 in. wide by 984 ft long (Figure 1, No. 1).

c. Other materials:

(1) Rock: limestone (size given in Table 1).

(2) Sand: SP concrete type.

(3) Concrete mix: Sakrete.

(4) Sand bags: burlap fabric; 10-oz material; 18 in. wide by 26 in. long.

PART III: LABORATORY TESTS AND TEST RESULTS

Tests

8. Laboratory tests were conducted to determine the physical characteristics of the membranes and filter fabrics used in this investigation. These tests were conducted in accordance with Federal Test Method Standard No. 191 and American Society for Testing and Materials Standards (ASTM) as applicable to coated and nonwoven materials. The Instron testing equipment (Photo 1) was used to determine the grab, trapezoidal tear, elongation, and joint-breaking strength. Photos 2 and 3 show a typical setup before and after the test.

Results

9. Results of the laboratory tests are presented in Table 2 and Plate 1. The tensile strength versus elongation physical characteristics developed by the T15 and T16 membranes were the highest for the membranes tested. The Bidim C-38 developed the highest tensile strength versus elongation characteristics of the filter fabrics.

PART IV: FIELD TESTS AND TEST RESULTS

10. A field test site for placement of the materials described in paragraph 7 was selected along the bank slope of the Big Black River (Plates 2 and 3) adjacent to the U. S. Army Engineer Waterways Experiment Station (WES) Big Black River test facility. This site is located at approximately mile 53 above the mouth of the river. A view of the right bank of the river along the test area before the materials were installed is shown in Photo 4. This view looking upriver is approximately at the midpoint of the test area. Note that most of the bank is denuded of vegetation and trees as a result of rapid and frequent large fluctuations of river stages. Small trees and vegetation can be seen near the top bank. The uppermost part of the bank was almost vertical with a height that varied from 6 to 10 ft. The major portion of the bank was sloped approximately 18 deg. Note the slope indicator (33 percent) in the left portion of Photo 4.

11. The water level in the river occasionally remains high for periods as long as 30 days or sometimes longer; however, the level has dropped as much as 14.1 ft in a 48-hr period (Table 3). Thus bank sluffing, sliding, and erosion (Photo 4) occurred all along the riverbank. These conditions resulted from saturated banks and rapid drawdowns of the water level of the river.

12. Prior to installation of test materials at the Big Black River test site, a permit had to be obtained from the Corps of Engineers, Vicksburg District. A request for this permit was submitted to the Vicksburg District on 16 May 1979. The Vicksburg District in turn was required to conduct an evaluation in accordance with Section 404(b) of the Clean Water Act. This evaluation was conducted and approval for the project on the Big Black River was received on 28 September 1979.

13. During the period that the permit to conduct the work on the bank of the Big Black River was being processed, an alternate test site was selected. The alternate site was located on Durden Creek, which flows through the WES Test Facility (Plates 2 and 4). There were two main purposes for selecting an alternate test site. One was to verify

experimental construction and placement techniques, and the other was to collect limited field data on the performance of experimental materials used for erosion control purposes in case the request for a permit for the Big Black River tests was denied.

Durden Creek

Test site

14. The area selected for test purposes along Durden Creek had been eroded previously by high-water stages and streamflows as shown in Photos 5 and 6. The creek test area was subject to being covered by water after heavy rains, and high-water conditions had been observed for periods up to 8 hr as shown in Photo 7. Since the water level fluctuated as much as 7 ft during periods of heavy rain and these conditions were found to have occurred many times in the past, this site was selected for evaluation of experimental materials and construction techniques.

15. The bank just upstream of the test area curved (Photo 5) to the extent that it permitted the construction of a diversion channel that allowed the water to be pumped from the area where the test materials were to be installed (Photo 8). Dams were placed at each end of the test area; however, after these dams were overtopped when heavy rains occurred (Photo 9), the water had to be pumped out so the bank would dry before work could continue on the test area. The placement and the installation of materials were made along the creek bank just below the normal low-water level at the toe and continued up the bank slope to a location approximately 2 ft above the top bank. The existing in-place soil in the test area was identified and classified as a silt (ML) (Plate 5).

Test items*

16. Seven different test items (Photo 10 and Plate 6) were installed on the test area with each item being approximately 17 ft wide

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* Materials installed as test items described in paragraph 7 and Table 1.

(parallel to streamflow) and 20 ft long (perpendicular to streamflow). These items included:

a. A stepped membrane-encapsulated soil layer (MESL) with the T15 membrane used as the encapsulating material installed along the bank in an area where the bank had caved vertically (Item 1).

b. Four "blanket" items, the T15 (Item 2), Hypalon 10×10 (Item 3), Hypalon 5×5 (Item 4), and T16 (Item 5) membranes, draped over the slope of the bank and anchored in ditches with the ditches being backfilled partially with soil and then covered with sandbags.

c. A MESL item with the T15 membrane used as the encapsulating material (Item 6).

d. Bidim C-34 filter fabric covered with riprap (Item 7). The riprap-covered filter fabric was used as the performance standard, and its performance was compared with that of other test materials.

Construction and installation methods

17. A dragline removed vegetation from the test area before the test area was shaped with a D-4 dozer (Photo 11). A backhoe removed the soil from the area where the bank had caved vertically (Photo 12). This caved area was used for the stepped MESL item (Item 1). A dragline (Photo 13) was used to excavate the soil to the depth required for construction of the encapsulated MESL (Item 6) and riprap (Item 7) items. Approximately 10 in. of soil were removed for construction of these items. Anchor ditches were constructed with a hand-operated Ditch Witch machine (Photo 14). The ditches measured about 18 in. wide and 18 in. deep. Sandbags were filled by hand using shovels. These sandbags were used for anchorage in the ditches and ballast on the membrane.

18. The methods used to install the materials on Durden Creek are described below.

a. Stepped membrane encapsulated soil layer (MESL), Item 1. Horizontal steps were constructed using the MESL technique* to envelope soil layers. The base used for

* S. L. Webster. 1974. "Construction of MESL Demonstration Road at Fort Hood, Texas, May 1972," Miscellaneous Paper S-74-13, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

constructing the steps consisted of two layers of sandbags. Initially, a sheet of T15 membrane was first placed over the sandbag base so that approximately 4 ft of material was provided at the sides and ends to overlap the sandbag form used to retain the loose sand* backfill. The form was constructed with sandbags so that (Photo 15 and Plate 6, sheet 3) a 15-in.-high by 15-in.-wide wall was formed at the periphery of the step (except along the wall of the bank slope) to contain the loose sand placed (Photo 16) in the step. After the area bounded by the sandbag form was filled with sand, the top half of the membrane was placed over the backfilled step, the sides were anchored with sand and sandbags, and the uppermost edge was anchored on the slope with tack anchors (Photo 17). Photo 18 shows the membrane-covered steps completed as a part of the bank protection.

b. Blanket, Items 2-5. In the construction of the blanket, anchor ditches were first constructed approximately 18 in. deep at the periphery of the area to be surfaced (Photo 19). The bank area bounded by these ditches was then covered with the "blanket" of membrane (Photo 20). When the membrane was positioned and stretched tight, the edges were placed in the ditches and secured with tack anchors spaced 6 to 8 ft (Photo 21). After ditches were filled with compacted backfill to within a few inches of the top, sandbags were placed over the compacted backfill for anchorage and to prevent the backfill from erosion. Plate 6, sheets 4-6, gives complete details of the blanket items. Photos 22-25 show the completed test items (2-5).

c. MESL, Item 6. This method of construction is similar to the installation of the stepped MESL. A sheet of membrane was placed in the area where the soil had been excavated previously to the desired depth (10 in.). A sandbag form was constructed at the periphery of the test item (Plate 6, sheet 6). Approximately 4 ft of membrane was extended outside the sandbag form on three sides of the item. At the upstream edge of the item, additional membrane was provided so that it was adequate to cover the top of the backfilled area when it was filled with loose sand (Photo 26). After the sandbag form was filled with sand, the membrane along the sides of the box was overlapped (Photo 27) and then the top membrane sheet was pulled over the sand backfill (Photo 28). The edges of the membrane at top bank and at the toe were anchored in ditches as described

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* See Plate 7 for gradation of sand used as backfill and for sandbags.

previously for the blanket items. The downstream edge of membrane was anchored with tack anchors (Photo 29) and riprap (Item 7) placed over the edge. Normally, in areas where the MESL concept is used alone, the membrane edge would be anchored in a ditch. Photo 30 shows the completed item.

d. Bidim C-34 filter fabric covered with riprap, Item 7. The Bidim C-34 fabric had been placed on the bank prior to the anchoring of the T15 membrane on Item 6 as described in c above. Tack anchors were used every 6 to 8 ft to secure the fabric in place (Plate 6, sheet 7), and riprap 10-12 in. deep was placed over the fabric (Photo 31). Photo 32 shows the completed item.

Monitoring and data collected

19. The performance of the materials was monitored from August 1979 through December 1980. Various test data including photographs, cross sections (Plate 8), rainfall data (Table 4), stream velocities, and discharge measurements (Table 5) were collected.

20. Velocity measurements were taken from a bridge located approximately 75 ft upstream from the test area. Measurements were taken at stations established on the bridge using a Gurley current meter. The meter was suspended from the bridge by a cable with a 50-ft weight attached below the meter to prevent downstream movement (Photo 33).

21. Data obtained by field measurements was used to compute discharge by means of an expression that summated partial discharges, which were computed by using the observed depth and mean velocity in the vertical and from the station distance measured between verticals.

22. In Figure 2, d_o , d_1 , d_2 , ... , d_n represent the

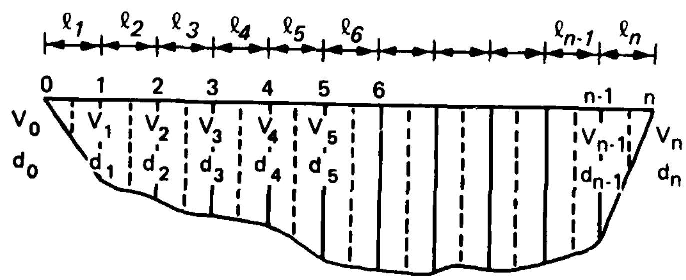


Figure 2. Field observations for current-meter measurements of discharge

measured depths of verticals; ℓ_1 , ℓ_2 , ℓ_3 , ... ℓ_n are the respective distances between verticals; V_o , V_1 , V_2 , ... , V_n represent velocities in the verticals. Each metered vertical and its measured depth are assumed to be the mean of a zone extending from the vertical halfway to the vertical on each side. A summation of the partial discharges computed for each zone is equal to the total discharge Q , which may be expressed as

$$Q = V_o d_o \left(\frac{\ell_1}{2}\right) + V_1 d_1 \left(\frac{\ell_1 + \ell_2}{2}\right) + V_2 d_2 \left(\frac{\ell_2 + \ell_3}{2}\right) + \ldots\ldots\ldots + V_{n-1} d_{n-1} \left(\frac{\ell_{n-1} + \ell_n}{2}\right) + V_n d_n \left(\frac{\ell_n}{2}\right)$$

Test results

23. Experimental materials used as test items at Durden Creek performed satisfactorily during the period reported. During this period, the water level in the creek varied from the toe of materials to near top bank (Photo 34) a minimum of 50 times. The water level fluctuated as much as 7 ft within a 4-hr period as the result of heavy rains, which caused high-water levels for periods up to 8 hr. Maximum stream velocities of 3.9 fps and discharges up to 280 cfs were recorded.

24. There were only two problem areas observed with the use of the test materials. One of these was with the T15 membrane used as the second step of the stepped MESL item (Item 1), which "ballooned" after placement (Photo 35). This condition caused by air entrapped beneath the membrane occurred after the water had risen in the creek several times. The ballooned area was observed to increase and decrease with ambient temperatures, and it was approximately 3 ft wide and 8 ft long (Photo 36) near the end of observations recorded for this report. No damage to Item 1 was observed, and the ballooning had not affected the performance of adjacent test items. The other problem involved sandbags used for ballast in anchor ditches and on the membranes. The bags made of burlap material deteriorated (Photo 37); as a result, rains and streamflows leached the sand from the bags. When construction began at the Big Black River test site, the first problem, ballooning, was

eliminated by stretching the membrane taut on each step and placing ballast of sacked concrete at the face of each step to prevent ballooning of the membrane. The second problem was also solved by using sacked concrete mix in anchor ditches and in other areas where ballast was required. The original sandbags used at Durden Creek were replaced during October 1980 with bagged concrete mix, and ballast consisting of sacked concrete mix was placed at the face of each step of the stepped MESL item (Item 1). The air observed to be entrapped beneath the membranes (Items 5 and 6, Photo 38) during high-water levels in the creek did not cause any noticeable effects on these materials. In fact, this condition helped to raise the height of the top bank and prevented flood waters of the creek from overtopping the bank in this area. As the high water receded, the membrane returned to its original position on the slope of the bank. The bank in the test area of Durden Creek remained stable as a result of the protection provided by test materials.

Cost

25. The total cost of the project on Durden Creek was $31,300, which included a material cost of $6,800. Table 1 lists the unit material costs. The total cost was high due to the large number of heavy rains that occurred during construction. The rains caused water to overflow the low-level dams used to block the normal creek flows from the test area, and each time the rain storms occurred, the banks at the site were saturated. When the high water receded, the water trapped between the dams was pumped out and the banks were allowed to dry. Construction was initiated in June 1979, and installation of materials was completed during August 1979.

Big Black River

Test site

26. The bank on the Big Black River selected for the test site has been previously described in paragraphs 10 and 11. The soil identified at top bank was a lean clay, while 20 and 40 ft from the top bank, the soil was a sandy clay (Plate 9). Cross sections of the bank shown

in Plate 10 were obtained prior to construction and installation of materials.

Test items*

27. Seven different test items (Items 2-8, Photo 39 and Plate 11) and one tie-in item (Item 1) were installed at the test site. Each item was approximately 22 ft wide (parallel to water flow) and 42 ft long (perpendicular to streamflow). Items shown in Photo 39 are identified as follows:

Item 1 - riprap placed on Bidim C-38 filter fabric.

Item 2 - blanket of Hypalon rubber-coated 5×5 polyester scrim membrane.

Item 3 - blanket of Hypalon rubber-coated 10×10 polyester scrim membrane.

Item 4 - blanket of T15 membrane.

Item 5 - blanket of T16 membrane.

Item 6 - MESL constructed with T15 membrane.

Item 7 - riprap placed on Bidim C-38 filter fabric (standard of comparison item)

Item 8 - stepped MESL constructed with T15 membrane.

The bank area below the toe anchor ditches was covered with 10 to 12 in. of riprap placed on Bidim C-38 fabric. This area was approximately 6.5 ft wide (Plate 11) and ran the length of the test area. The distance from the lower edge of the riprap placed at the toe to the normal low-water level was about 20 ft. Because riprap larger and heavier than that used at Durden Creek was required for the Big Black River project, a heavier material, Bidim C-38 filter fabric, which was also stronger than Bidim C-34, was selected and used.

Construction and installation methods

28. A dragline was used to expedite removal of vegetation from the test area. Photo 40 shows the bank area after the vegetation was removed. The area of the bank selected for the stepped MESL item (Item 8) can be seen in this photograph. This area had sheared near the

* Materials installed as test items described in paragraph 7.

top bank, slipped toward the river, and eroded away leaving a gap in the bank. After the vegetation was removed, the bank was shaped with a D-7 dozer. Photo 41 shows the shaped bank and excavation of the soil for Item 1 so that the required depth (10-12 in.) of riprap could be placed on this area. Soil was also excavated in this manner from the bank in the areas used for Items 6 (MESL item) and 7 (riprap on Bidim C-38). A front-end loader was used for placing soil and riprap during the installation of test materials.

29. Anchor ditches (18 in. wide by 36 in. deep) parallel to streamflow were constructed with the equipment shown in Photo 14. The ends of the membrane were anchored in the ditches with tack anchors spaced 6 to 8 ft apart. The ditches were then backfilled and compacted to within about 6 in. of the surface, and riprap was placed on the compacted backfill (Plate 11, sheet 3). The anchor ditches (36 in. wide by 40 in. deep), constructed perpendicular to the flow of the river, were also used for sand drains (Plate 11, sheets 3-5) to relieve hydrostatic pressure should it develop behind the materials on Items 2-6 and cause ballooning and blowout during rapid drawdown of the river. These ditches were excavated with a backhoe. These combination anchor/sand drain ditches were first lined with Bidim C-38 fabric (Photo 42), and then approximately 6 in. of sand was placed in the ditch. A polyvinyl chloride (PVC) perforated pipe wrapped with Bidim C-38 fabric was placed (Photo 43) on top of the sand for the entire length of the ditch. Near the toe end of the ditch, the pipe was closed with a perforated cap and covered with washed gravel (Photo 44 and Plate 7) to allow water to drain from the bank without causing localized erosion of the bank. Sand was then placed over the remainder of the PVC pipe to within 18 in. of the surface and encapsulated with the Bidim C-38 fabric (Photo 45). Riprap was placed over the washed gravel at the toe of the ditch. Approximately 12 in. of backfill (Photo 46) was placed over the encapsulated sand, and riprap was placed over the compacted backfill (Photo 39) to complete construction of the anchor/sand drain ditch.

30. The installation methods used at the Big Black River test site are described on the following page:

a. Bidim C-38 filter fabric covered with riprap, Items 1 and 7. The soil in the area for Items 1 and 7 was excavated approximately 12 in. (Photo 41). A 4- by 4-ft ditch was dug at the upstream edge of Item 1 for placement of riprap in order to prevent undercutting of this test item by flows of the river. Photo 47 shows this ditch with Bidim C-38 placed and anchored and the membrane for Item 2 being anchored on the upstream edge. Tack anchors were used every 6 to 8 ft to anchor the Bidim fabric and the Hypalon 10×10 membrane in the anchor ditch. Photo 48 shows approximately 12 in. of riprap being placed with a front-end loader on the Bidim fabric. Plate 11, sheets 1-3, gives details of the installation. Photo 49 shows construction completed on these items. Item 1 was considered as the transition between the unsurfaced bank upstream and the test items (Items 2-8). Item 7 contained riprap placed over Bidim C-38 filter fabric (Photo 57 (also includes Item 8) and Plate 11, sheets 1 and 7) and was the standard item compared with the performance of the other test items. The installation of the materials on Item 7 was similar to that described for Item 1.

b. Blanket, Items 2-5. The techniques and construction methods used to place these items were similar to those described in paragraph 18b for "blanket" materials placed on Durden Creek. The anchor ditches were constructed as those described in paragraph 29. Photos 49 through 51 illustrate these items when the construction was completed. Plate 11, sheets 1, 3, and 4, provides details of construction used for these items.

c. MESL, Item 6. The installation methods used to place this item were similar to those described in paragraph 18c for the MESL item (Item 6) on Durden Creek. However, there were two differences between the methods used on this item and Item 6 on Durden Creek. The form constructed around the periphery (Photo 52) of this item was made with bagged dry concrete mix. After placement, the bags were sprayed with water, and the mix was allowed to cure before the backfill was placed within the form (Photo 53), compacted, and encapsulated with membrane. Edges and ends of the membrane were anchored as shown in Plate 11, sheets 1 and 5. Photo 51 shows the completed test item.

d. Stepped MESL, Item 8. The installation methods used to place this item were similar to those described in paragraph 18a for the stepped MESL on Durden Creek. However, there were two differences between the methods used for this item and Item 1 on Durden Creek. The form constructed to contain the loose sand backfill was 18 in. high (three bags high) and 30 in. wide (two rows of bags).

The bags contained concrete mix rather than sand, which had been used for Item 1 on Durden Creek. The other difference was that all slack was removed from the membrane as it was pulled taut, and on the leading edge (Plate 11, sheets 8-9) of each step, bagged concrete mix was used to secure the edges of the steps and prevent ballooning of the membrane. Photo 54 shows the area of the bank for this item prior to placement of materials. This area was previously described in paragraph 28 and shown in Photo 40. Very little preparatory work was required to shape this area prior to construction of the steps. A base consisting of one layer of bagged concrete mix was placed prior to placement of the membrane for the first step. Photo 55 illustrates the partially completed first step of the item with the edge of the membrane being overlapped at the sides before placement of top sheet of membrane. Photo 56 shows the top sheet of membrane being placed over the loose sand backfill used to construct the step. The end of this top sheet was anchored on the sloped bank with tack anchors and along the edges with riprap and bagged concrete mix (Plate 11, sheets 8-9). Photo 57 presents the completed item. Photo 58 shows the eroded bank just downstream from this item. The soil beneath the tree roots and along the bank had eroded prior to the installation of the materials on the test area.

31. The membrane was damaged during construction of some of the items when the riprap was placed (Photo 59). This damage occurred when some of the riprap being placed was dropped accidentally and fell on the membrane near the edge that covered the bagged concrete mix form. These areas were patched (Photo 60) with adhesives secured from the material supplier and swatches cut from pieces of membrane left over after placement of the items.

Monitoring and data collected

32. The performance of materials was monitored from November 1979 through December 1980. Various data such as cross sections (Plate 12), rainfall data (Table 4), water velocities and discharge measurements (Table 5, Plate 13, and Photo 61), and river stages (Table 6, Plate 14, and Photo 62) supplemented with photographs were collected.

33. Two piezometers were located in the vicinity of the test area: one about 10 ft from the top bank adjacent to Item 2 (Photo 63), and the other about 200 ft southwest of the top bank of the test area. The

readings in Table 6 were taken from the piezometers periodically to determine the location of groundwater. As the river rose, the groundwater level was usually within a foot or so of the level in the river.

Observations and performance of materials

34. In mid-November 1979 (Photo 64) the river began a slow rise with slight fluctuations until the latter part of November, at which time it rose to the top bank during the first week in December (Photo 65). After the peak stage was reached near the top bank, the water level fell slowly until it reached a level between the half bank and the toe of the materials. It fluctuated around this level until 10 January 1980. Large deposits of silt were left on the test materials each time the water level of the river dropped slowly (Photo 66). From this time until the latter part of February, the water level was such that at least 50 percent or more of the test bank was covered with water because of heavy local and upstream rains. During the last week of February 1980, the water level dropped slowly for several days, and then there was a sudden drop of 10.7 ft in 48 hr (Table 3). The water level at this time was below the toe of the materials. Some shifting and sluffing of the bank at the toe of the materials (Photo 67) occurred as well as along the riverbank in areas not associated with the test area (Photos 68 and 69). There was no damage observed to the materials on the test items although the riprap at the toe anchor ditches had shifted.

35. The water level remained below the toe of the materials for about 10 days. A slow rise then began, and the water overtopped the bank because of heavy local and upstream rains (Photo 70, 31 March 1980). The water remained at this level or near the top bank for about 15 days. A slow fall began until the level reached about half bank. Photograph 71 shows the damage caused to the top bank area adjacent to Items 5 and 6 as the water overflowed the top bank. This damage resulted even though the top bank area was covered with a thick, heavy rye grass sod. The depth of the eroded areas varied from 10 to 12 in. The water level fluctuated between half and top bank until 9 May 1980 (Photo 72). Between 9 and 12 May 1980, the water level dropped 13 ft

(60-hr period). Photo 73 presents the condition of the test area on 12 May. The test materials on all items were damaged and torn (Photos 74-76) because of bank failure. Since March, the bank behind the test materials had been saturated with water, and then the sudden drawdown caused the bank to fail, resulting in the failure of the test materials. The riprap on Item 7 (standard for comparison) also settled and shifted. Sliding and shifting of the bank also occurred upstream (Photo 77) and downstream (Photo 78) of the test area.

36. The water level remained at or near the toe of the test materials for about 7 days, then a slow rise began in the water level until about two thirds of the test bank was covered on 26 May 1980. The level then dropped 12 ft in 48 hr, at which time the water was again below the toe of the materials. Some minor additional shifting of the bank and tearing of the membrane materials occurred caused by displacement of the bank.

37. The water level rose only twice during the summer months to the point where about one third of the bank was covered with water. These changes in the water level were slow and caused little additional damage to the bank. Photo 79 shows the condition of the bank in July 1980 as volunteer vegetation and bushes (cottonwood and willow) began to grow in areas that can be seen at about half bank. Vegetation and bushes did not emerge on the lower part of the bank as the river covered this part of the bank several times during the growing season. Photos 80 through 83 illustrate closeup views of the vegetation and small bushes growing on the bank as well as the condition of Items 1 through 8. Areas of the bank that shifted and failed during sudden drops of the river caused the riprap to settle and move (Items 1 and 7) and ultimately tear membrane materials (Items 2-6 and 8). These conditions can also be observed in these photographs.

38. The shifting and sliding of bank areas (paragraphs 34-37) that occurred upstream and downstream in areas not associated with the test area also occurred throughout the river basin. Photos 84 through 86 are the views of the riverbank approximately 3 miles downstream from the test area where the bank failed as a result of long periods of high water

followed by rapid drawdowns of the water level. This condition occurred during the same period that the bank at the test site failed and caused damage to test items. Dashed lines have been drawn on Photos 84 and 85 to illustrate the location of the tree line before bank failure occurred. The trees and bank area shown to the left of the lines drawn on Photo 84 are shown after bank failure and displacement in Photos 85 and 86. Some of the trees remained on the lower slope of the bank, whereas others slid into the river. When this drawdown condition on the river occurred, soil was eroded from around a bridge pier immediately downstream and adjacent to the area described above. Photo 87 shows the condition of the bridge pier located on Mississippi Highway 27.

39. The river level remained well below the toe of the materials until late October 1980, and then it rose until about one third of the bank was covered with water. The fluctuation between this level and below the toe of the material continued through December 1980. At this time, no additional bank failures or damage to test items was observed.

Cost

40. The total cost of the project on the Big Black River was $52,600, which included a material cost of $24,800. Table 1 lists the unit material costs. The construction costs are considered high because several pieces of heavy equipment were used to expedite construction before the rainy season occurred. Also, for several weeks river stages had been unusually high due to heavy rains from a hurricane. Therefore, initiation of construction was delayed even further as the permit to conduct the project was not approved until 28 September. Normally, the membrane-type materials can be installed with a minimum amount of light construction equipment and hand labor even though more time may be required for installation. Construction on the project was initiated on 9 October 1979, and material installation was completed on 3 November 1979.

Rehabilitation

41. During project construction, high-water stages caused by rains occurred on the river and saturated the lower bank in the test area. Thus the placement of protective materials down to the area where

the normal mean low-water level occurs was prevented. Plans were then made to do additional work on the test area between the toe of the materials placed and the low-water level. This work was to be done after the water level had fallen and remained at this low stage for a period of time that allowed this part of the bank area to dry adequately before the work could be initiated. The plans also included placing riprap over filter fabrics as an aid in stabilizing the bank from the toe of the materials to the mean low-water level. However, during the winter and spring months of 1979 and 1980, respectively, river stages peaked and fluctuated followed by several drawdown conditions in the river that caused extensive bank failures. Therefore, the original plan which recommended that additional riprap be placed on the lower bank area was abandoned, and an effort to aid the natural reestablishment of trees and vegetation on the top portion of the bank was initiated by planting cottonwood and willow tree sprigs during January 1981. The planting and placement of these sprigs is covered in Appendix A. Sprigs were planted in rows from the top bank to approximately half bank as this area was about as far down the bank that existing trees were observed to be established upstream and downstream of the test site.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

42. The following conclusions are believed warranted as the result of tests, data collected, and observations made on Durden Creek and the Big Black River:

- a. On Durden Creek, all membrane materials used performed satisfactorily by protecting the bank from failure. Each type of technique used for installation of the membrane materials performed satisfactorily, i.e., blanket, stepped MESL, and MESL items.
- b. On the Big Black River, all membrane materials used in the tests and each type of installation (blanket, stepped MESL, and MESL) of the materials performed satisfactorily in protecting the bank from erosion until heavy rains occurred that not only saturated the areas adjacent to the top bank but also caused high stages on the river. These bank conditions were aggravated additionally by the water in the river that caused flooding by rising over the top bank and remaining at this level for an extended period of time. As the result, banks not only in the test area but all along the river basin became saturated and unstable. The water level in the river fluctuated to such levels and with such rapid drawdowns (coupled with the saturated banks and areas adjacent to the bank) that the bank failed, resulting in material failures at the test site. Numerous areas of the riverbank both upstream and downstream of the test area also failed during these rapid fluctuations of the river.
- c. Membrane materials will protect streambanks and riverbanks from erosion during normal streamflows as long as banks remain stable. It is doubtful whether any known methods of construction and materials will prevent erosion after the banks fail.

Recommendations

43. Based on field tests results, the following recommendations are believed warranted:

- a. Membranes should be used to prevent erosion when installed as blankets, stepped MESL, or MESL sections. Field performance and material costs indicate the cost effectiveness of membrane materials installed as temporary protection of streambanks.
- b. The type of installation method is determined by the

condition of the bank where protection is provided. The blanket method (Plate 11, Items 2-5) can be used where the bank requires a protective surface from current and wave action. The MESL section (Plate 11, Item 6) can be applied when a heavy-type protection is required to prevent surface erosion. The stepped MESL method (Plate 11, Item 8) can be used in areas where the bank has caved vertically or nearly vertically to eliminate extensive grading and shaping of the bank.

Table 1

Materials and Cost

Material	Size	Weight oz/yd^2	Thickness in.	Cost (1979)
T15 vinyl-coated nylon	50 × 50 ft	19.1	0.0261	\$ 0.29/ft^2
T16 neoprene-coated nylon	50 × 50 ft	16.0	0.0194	0.5775/ft^2
Hypalon 5×5 polyester scrim	50 × 50 ft	33.4	0.0370	0.535/ft^2
Hypalon 10×10 polyester scrim	50 × 50 ft	31.0	0.0340	0.585/ft^2
Bidim C-34	13 ft 10 in. × 984 ft	7.7	0.081	0.099/ft^2
Bidim C-38	17 ft 5 in. × 984 ft	8.1	0.093	0.124/ft^2
Rock (riprap)	*	--	--	21.00/ton
Sand	--	--	--	5.06/ton
Sandbags	18 × 26 in.	**	--	0.324/bag
Sakrete	80-lb bag	--	--	2.10/bag

* Limestone aggregate size

A. Durden Creek test site:

Standard Square Mesh, in.	Cumulative, Percent Passing
7	100
6	80-100
5	45-65
4	0-20

The cost shown for the riprap is for the material used at the Big Black River test site. The riprap used at Durden Creek was already on hand at the WES. It was procured for \$10.66/ton in 1975.

B. Big Black River test site:

125-300 lb - 10 percent maximum; 6-125 lb - 80 percent maximum; spalls under 6 lb - 10 percent maximum.

** Ten-ounce weight burlap fabric.

Table 2

Physical Characteristics of Membranes and Filter Fabrics

Type Material	Grab-Breaking Strength, lb D 751* Warp	Grab-Breaking Strength, lb D 751* Fill	Grab-Breaking Strength, lb D 1117* **	Grab-Breaking Strength, lb D 1117* †	Elongation Percent D 751 Warp	Elongation Percent D 751 Fill	Elongation Percent D 1117 **	Elongation Percent D 1117 †	Trapezoidal Tear Strength lb D 2263* Warp	Trapezoidal Tear Strength lb D 2263* Fill	Trapezoidal Tear Strength lb D 1117 **	Trapezoidal Tear Strength lb D 1117 †	Ball Burst, lb Method 5120.1††	Joint-Breaking Strength, lb✦	Thickness in. D 751	Thickness in. D 1117	Weight oz/yd^2 D 751	Weight oz/yd^2 D 1117
Membranes																		
T15	324	268	--	--	25.8	30.1	--	--	59	46	--	--	411	294	0.0261	--	19.1	--
T16	483	260	--	--	26.7	28.4	--	--	40	30	--	--	566	348	0.0194	--	16.0	--
Hypalon 5×5	144	166	--	--	20.0	25.8	--	--	49	52	--	--	177	184	0.037	--	33.4	--
Hypalon 10×10	254	263	--	--	25.0	30.7	--	--	66	87	--	--	315	243	0.034	--	31.0	--
Filter fabrics																		
Bidim C-34	--	--	197	205	--	--	58.4	65	--	--	97	96	259	NA	--	0.081	--	7.7
Bidim C-38	--	--	249	207	--	--	75.3	87.1	--	--	100	71	271	NA	--	0.093	--	8.1

* ASTM - American Society for Testing and Materials Standards as applicable to coated and nonwoven materials. Test procedures used for these tests were identical.

** Long dimension of samples parallel to roll length (machine direction).

† Long dimension of samples parallel to roll width (cross-machine direction).

†† Federal Test Method Standard No. 191.

✦ WES tests. (Sample size and test conducted the same as for grab-breaking strength. Samples cut so that factory lap joint is at the center of each one to determine joint strength.

Table 3

Rise and Fall of Water Level of Big Black River

Rise						Fall					
Project Year* 1979-1980			Prior Years**			Project Year 1979-1980			Prior Years		
Period	hr	ft	Period	hr	ft	Period	hr	ft	Period	hr	ft
23-26 Nov 79	72	14.6	01-04 Jan 72	72	16.2	10-12 Dec 79	48	14.1	23-27 Jan 72	72	15.4
10-11 Jan 80	36	10.1	24-25 Dec 73	24	19.1	19-21 Dec 79	48	7.0	03-09 Mar 74	72	12.0
12 Mar 80	12	8.0	23-24 Dec 74	24	16.9	22-24 Feb 80	48	10.7	05-07 Mar 75	72	15.1
15-18 May 80	72	12.1	12-13 May 75	24	19.2	09-12 May 80	60	13.0	04-08 Feb 76	96	15.3
24-26 June 80	48	12.0	16-17 Oct 75	24	17.0	27-29 May 80	48	12.0	02-05 Mar 76	72	11.1
27-30 Oct 80	72	12.1	06-10 Mar 76	72	13.6	04-06 July 80	60	15.2	12-15 Apr 76	72	12.2
						03-05 Nov 80	48	10.0			

* Data recorded during project year at Bovina, Miss., gage located at mile 61.7 above mouth of river.

** Data recorded at Bovina, Miss., gage located at mile 61.7 above mouth of river and published by Vicksburg District (publication titled "Stages and Discharge of the Miss. River and Tributaries in Vicksburg District").

Table 4

Actual Monthly Rainfall in Inches, 1969-1980*

Month	Year 1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Jan	1.25	2.08	3.00	7.25	5.57	17.66	4.70	4.85	5.72	5.17	14.96	7.13
Feb	3.62	2.80	6.34	3.92	4.84	4.52	6.41	2.98	2.36	2.47	7.06	2.93
Mar	4.71	4.94	6.82	6.75	16.78	4.25	8.40	13.14	7.27	2.64	3.13	11.74
Apr	4.80	1.89	5.07	2.68	7.90	6.52	4.08	1.55	8.06	2.84	9.65	9.33
May	1.75	2.88	8.75	5.43	5.30	4.38	9.84	4.71	1.60	10.30	4.67	5.67
Jun	2.39	5.80	2.43	3.55	1.22	2.17	6.12	3.94	2.68	1.31	2.93	2.97
Jul	3.24	4.58	3.02	2.25	2.87	2.25	2.78	4.91	5.13	1.15	5.77	3.00
Aug	2.71	2.98	6.13	2.38	1.78	2.68	4.09	0.41	4.09	3.45	4.12	0.53
Sep	0.27	2.58	3.79	3.52	3.87	4.29	2.25	2.00	2.37	1.77	5.15	3.75
Oct	2.88	12.09	0.19	3.21	5.77	2.75	8.84	2.82	3.74	0.24	2.86	4.91
Nov	1.76	2.33	1.22	4.11	8.31	3.23	5.06	3.29	9.28	2.97	5.19	3.63
Dec	10.70	4.06	7.10	8.54	10.18	9.53	2.59	4.92	3.09	6.24	5.06	0.97
Total	40.08	49.01	53.86	53.59	74.39	64.23	65.16	49.52	55.39	40.55	70.55	56.56

* Recorded at U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Table 5

Velocity and Discharge Data

Date	Water Stage ft msl	Location of Water on Test Section	Maximum Velocity ft/sec	Discharge ft^3/sec
		Durden Creek*		
11 July 1979	136.5	Half bank	3.8	150
20 Sept 1979	137.9	Within 18 in. of top bank	3.9	280
		Big Black River**		
18 Dec 1979	99.8	Toe of materials	2.7	4,850
15 Jan 1980	106.0	Half bank	2.5	6,760
24 Jan 1980	109.4	Three-fourths bank	3.0	8,900
22 Mar 1980	112.0	Top bank	2.5	9,300

* Velocities measured at 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6 of the measured water depth.

** Velocities measured at 0.2 and 0.8 of the measured water depth.

Table 6

Piezometer and River Stage Data

Date	Piezometer P_1, ft (msl)*	Piezometer P_2, ft (msl)	Big Black River Test Site Gage ft msl	Big Black River, Bovina Gage, ft msl**
11/07/79	29.0 (83.5)	24.1 (86.5)	87.5 (E)††	93.0
11/27/79	10.5 (102.0)	10.2 (100.4)	105.4	110.7
12/04/79	3.4 (109.1)	†	112.3	122.3
12/11/79	8.7 (103.8)	†	103.2	108.2
12/12/79	13.8 (98.7)	7.9 (102.7)	96.8	99.9
12/17/79	11.0 (101.5)	7.4 (103.2)	100.8	106.9
12/18/79	11.6 (100.9)	7.7 (102.9)	99.8	106.0
12/20/79	16.5 (96.0)	10.4 (100.2)	94.0 (E)	100.5
12/26/79	16.0 (96.5)	11.8 (98.8)	95.5 (E)	102.1
12/31/79	16.3 (96.2)	11.3 (99.3)	95.0 (E)	101.8
01/02/80	16.5 (96.0)	11.6 (99.0)	95.0 (E)	101.7
01/07/80	18.8 (93.7)	13.2 (97.4)	94.0 (E)	99.5
01/14/80	6.7 (105.8)	4.5 (106.1)	106.5	111.6
01/15/80	7.0 (105.5)	4.4 (106.2)	106.0	111.7
01/18/80	7.1 (105.4)	4.6 (106.0)	105.8	111.9
02/04/80	6.4 (106.1)	3.6 (107.0)	105.8	111.7
02/12/80	5.1 (107.4)	2.7 (107.9)	107.0	112.8
02/15/80	5.0 (107.5)	2.4 (108.2)	107.3	114.1
02/22/80	8.7 (103.8)	4.8 (105.8)	102.7	108.6
02/26/80	21.5 (91.0)	14.4 (96.2)	92.5 (E)	96.5
02/28/80	22.5 (90.0)	15.5 (95.1)	91.5 (E)	95.7
02/29/80	23.0 (89.5)	16.3 (94.3)	90.5 (E)	95.5
03/05/80	20.9 (91.6)	15.3 (95.3)	92.0 (E)	97.1
03/14/80	8.1 (104.4)	7.4 (103.2)	106.0	--
03/22/80	1.5 (111.0)	†	111.9	122.0
03/31/80	‡	‡	114.1	123.8
05/05/80	4.5 (108.0)	1.9 (108.7)	108.1	114.9

(Continued)

* P_1 located about 10 ft from top bank adjacent to Item 2. P_2 located about 200 ft southwest of the top bank of the test area. Numbers given represent the distance from ground level to groundwater level. Number in ( ) is the mean sea level (msl) water level. The ground level msl of P_1 and P_2 is 112.5 and 110.6 ft, respectively.

** Bovina gage located at mile 61.7; gage at test site located at approximately mile 53 above mouth of river.

† No reading taken; piezometer surrounded by water.

†† River stage estimated (E) as lowest staff gage level set at 96.0 ft msl.

‡ Piezometer covered with water.

Table 6 (Concluded)

Date	Piezometer P_1, ft (msl)	Piezometer P_2, ft (msl)	Big Black River Test Site Gage ft msl	Big Black River, Bovina Gage, ft msl
05/09/80	7.5 (105.0)	3.3 (107.3)	105.4	111.4
05/12/80	20.6 (91.9)	12.4 (98.2)	91.0 (E)	97.5
05/13/80	21.9 (90.6)	14.4 (96.2)	90.0 (E)	96.6
05/27/80	8.2 (104.3)	6.9 (104.3)	106.0	109.2
06/02/80	24.5 (88.0)	16.9 (93.7)	88.0 (E)	94.7
06/05/80	25.6 (86.9)	18.2 (92.4)	87.0 (E)	94.0
06/13/80	27.6 (84.9)	20.1 (90.5)	86.0 (E)	93.1
06/26/80	19.8 (92.7)	19.6 (91.0)	93.0 (E)	103.2
07/02/80	9.1 (103.4)	8.4 (102.2)	105.0	111.5
07/08/80	25.4 (87.1)	13.3 (97.3)	90.0 (E)	94.6
07/11/80	26.9 (85.6)	20.3 (90.3)	88.0 (E)	93.4
08/01/80	27.7 (84.8)	21.6 (89.0)	87.5 (E)	93.1
08/15/80	29.3 (83.2)	23.8 (86.8)	87.0 (E)	92.5
08/25/80	30.2 (82.3)	24.6 (86.0)	85.0 (E)	91.9
09/10/80	30.7 (81.8)	25.3 (85.3)	85.0 (E)	91.8
09/24/80	31.4 (81.2)	26.1 (84.5)	84.5 (E)	91.4
10/10/80	31.0 (81.5)	26.4 (84.2)	84.0 (E)	91.8
11/05/80	25.0 (87.5)	20.3 (90.3)	89.0 (E)	94.4

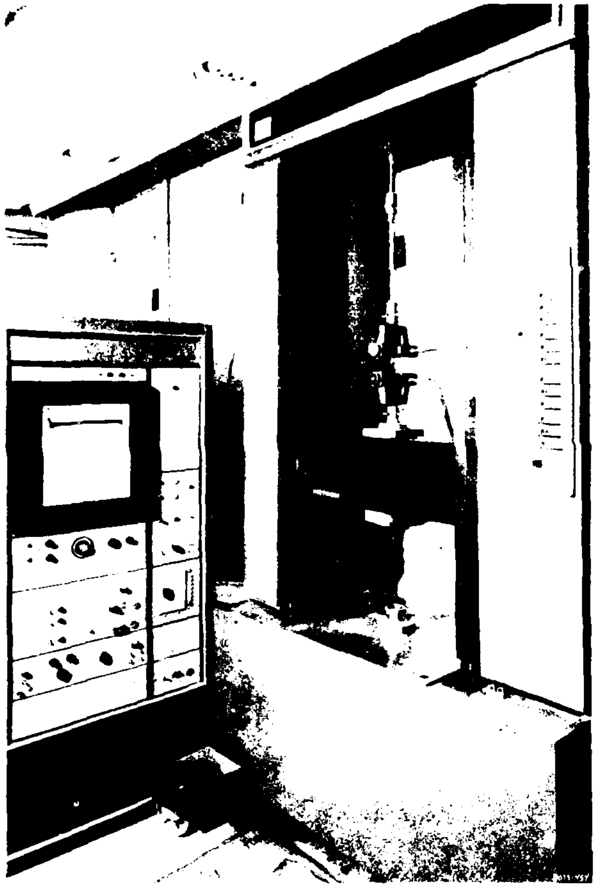


Photo 1. Instron testing equipment

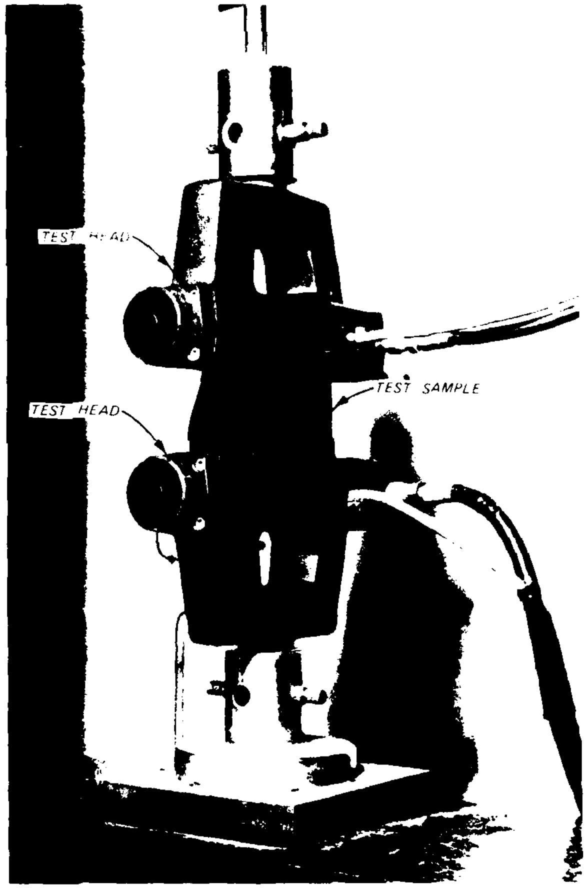


Photo 2. View of sample prior to test

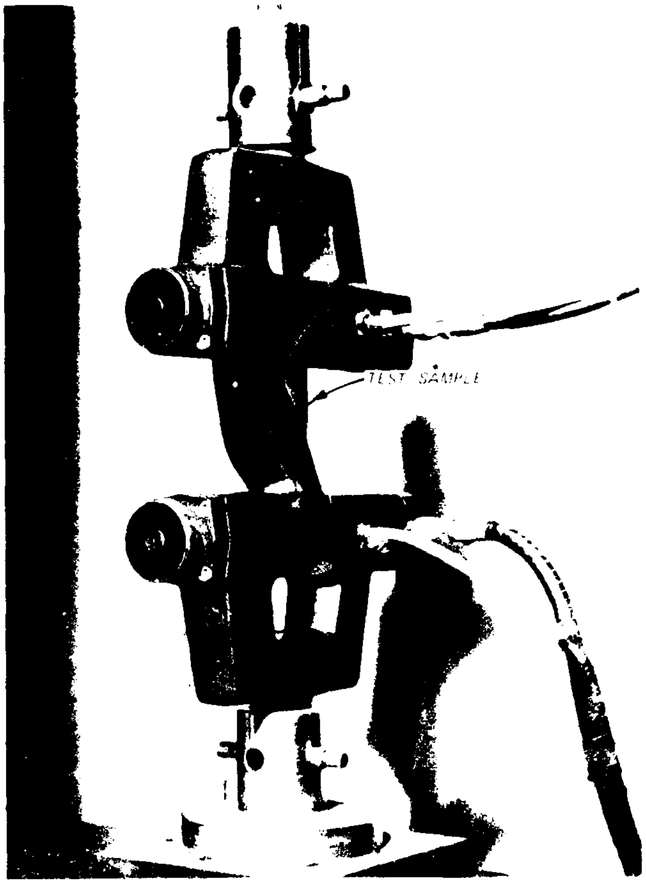


Photo 3. View of sample after test

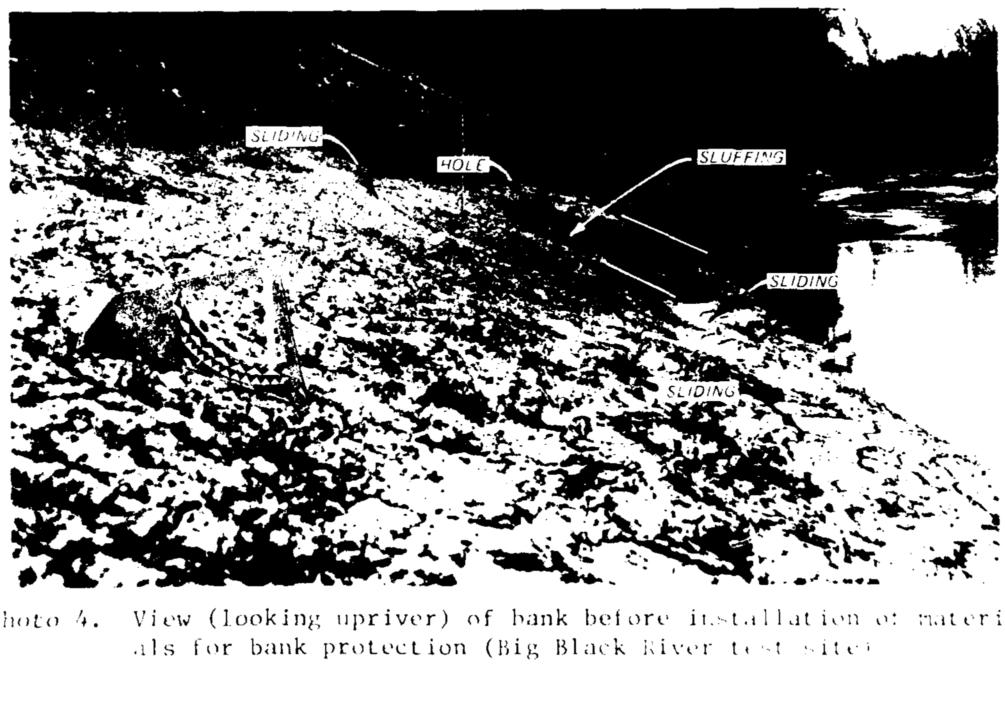


Photo 4. View (looking upriver) of bank before installation of materials for bank protection (Big Black River test site)

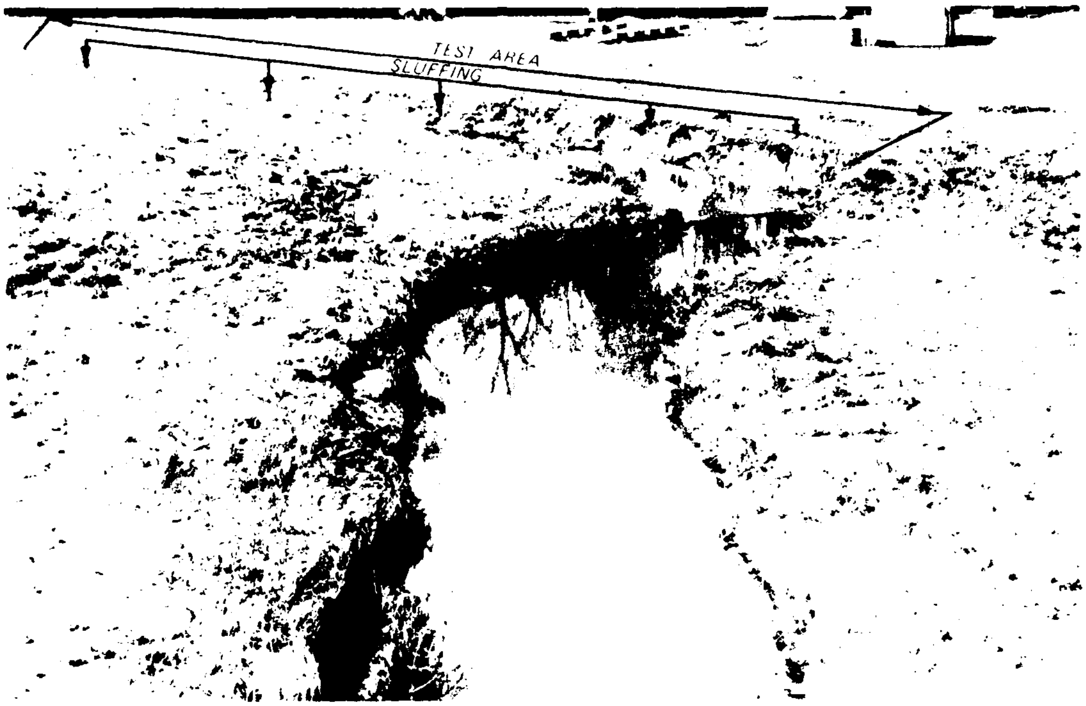


Photo 5. General view (looking downstream) of [illegible] for installation of test material

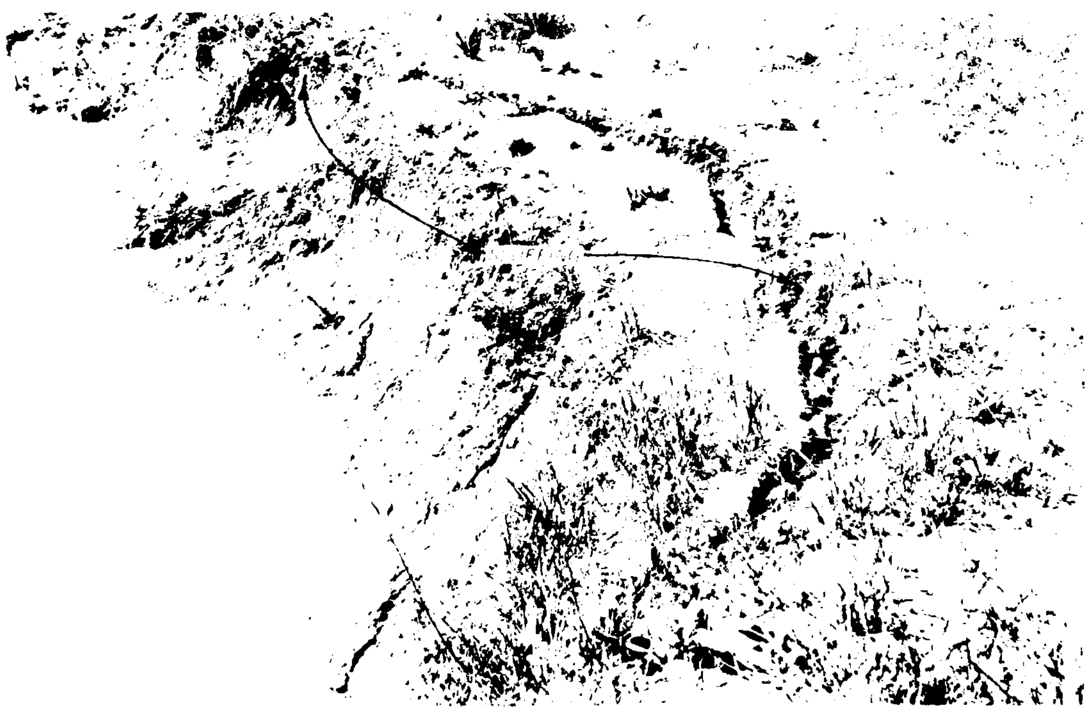


Photo 6. Close-up (looking downstream) of [illegible] Burden Creek

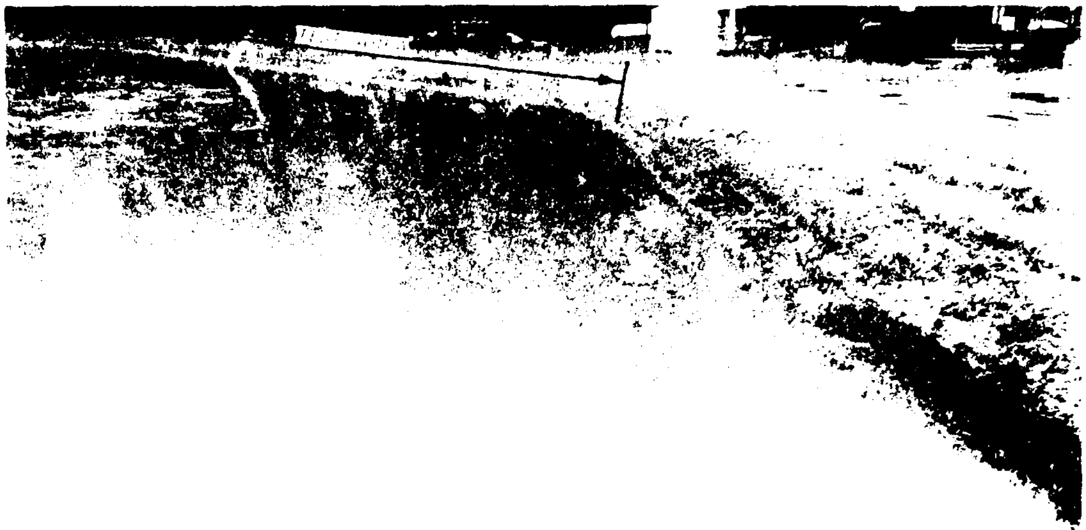


Photo 7. View (looking downstream) of Durden Creek test area after a heavy rain (prior to installation of test materials)

Photo 8. View (looking downstream) of diversion channel, dams and test area on Durden Creek

Photo 9. View (looking downstream) of test area after a heavy rain with water between the dams

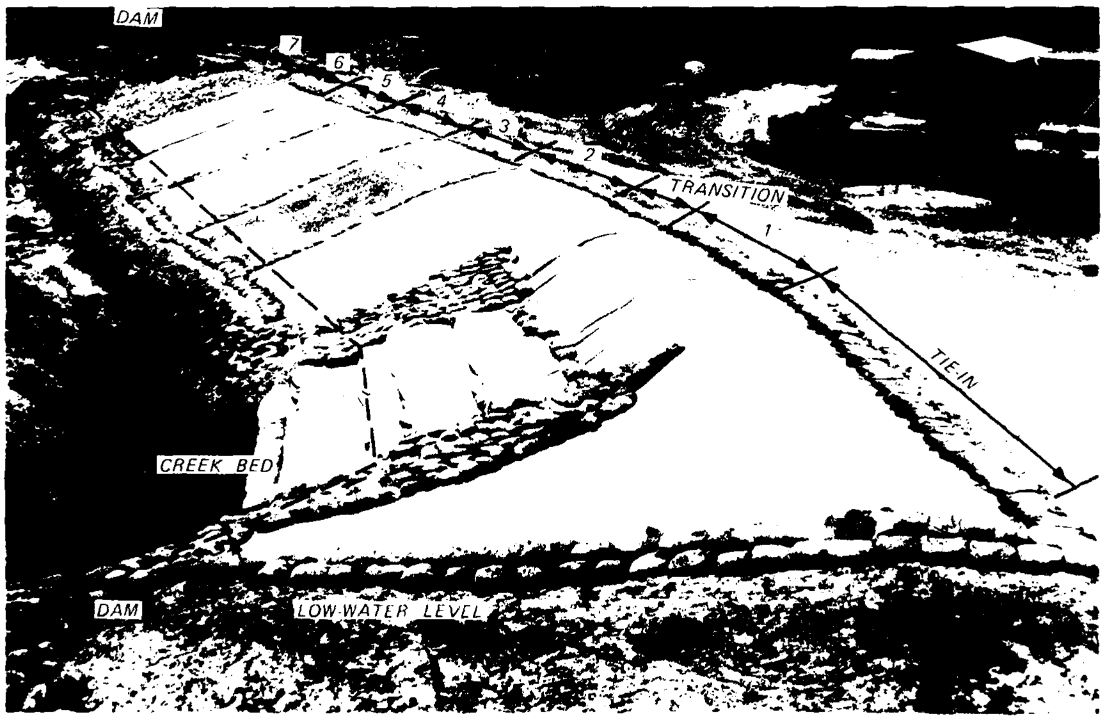


Photo 10. View (looking downstream) of the materials installed on Durden Creek (prior to removal of the dams)

Photo 11. View (looking downstream) of D-4 dozer used to shape the bank of the test area

Photo 12. View of backhoe used to remove soil from bank where soil was caving vertically

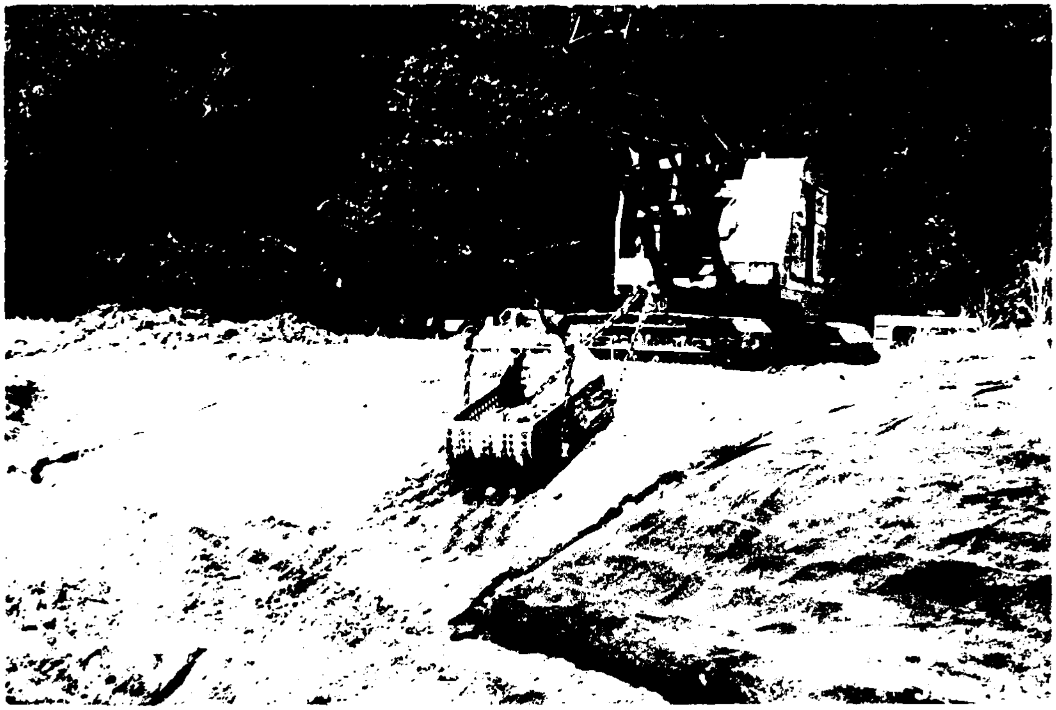


Photo 13. View of dragline excavating soil from bank area in Items 6 and 7

Photo 14. Construction of anchor ditch

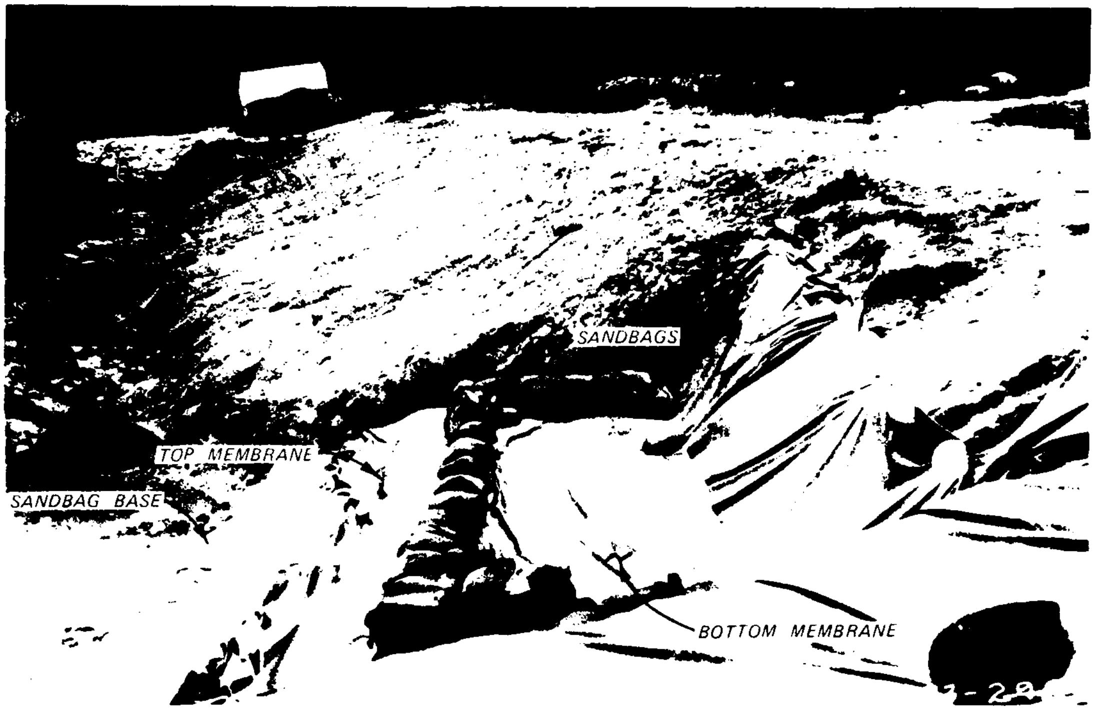


Photo 15. Typical form of sandbags used to confine loose sand backfill

Photo 16. Sand being placed in sandbag form of step

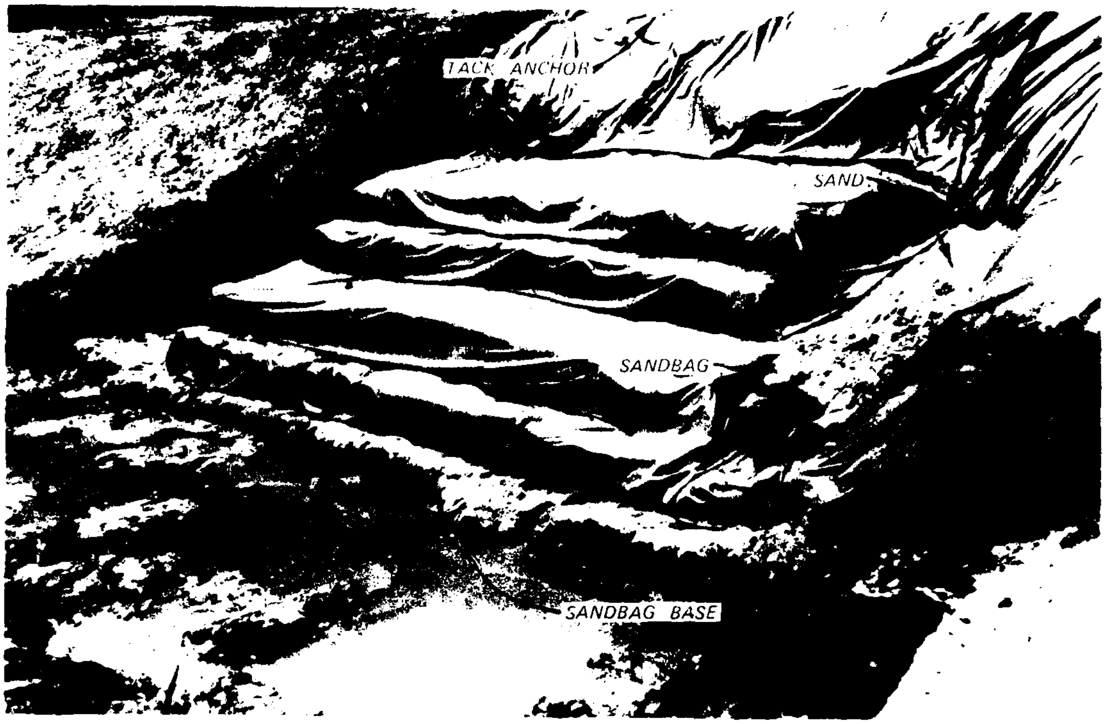


Photo 17. Completed steps of stepped MESL item

Photo 18. Item 1 - T15 stepped MESL

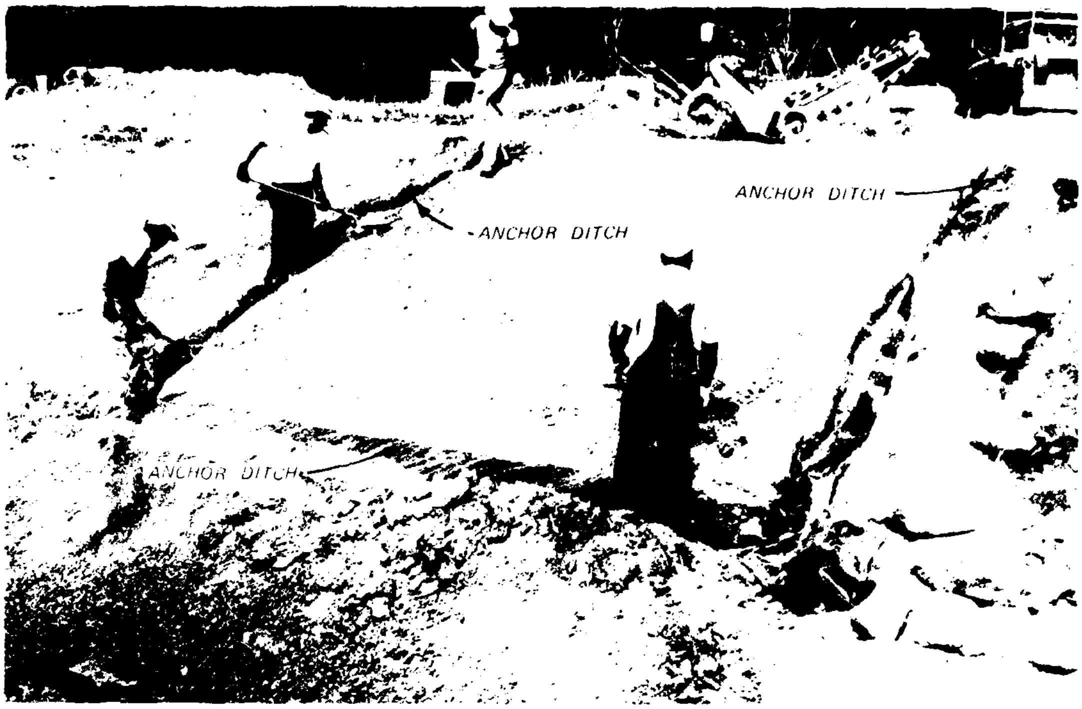


Photo 19. Anchor ditches constructed for a typical blanket item

Photo 20. "Blanket" of material being placed over the soil

Photo 21. Membrane secured with tack anchors in anchor ditch

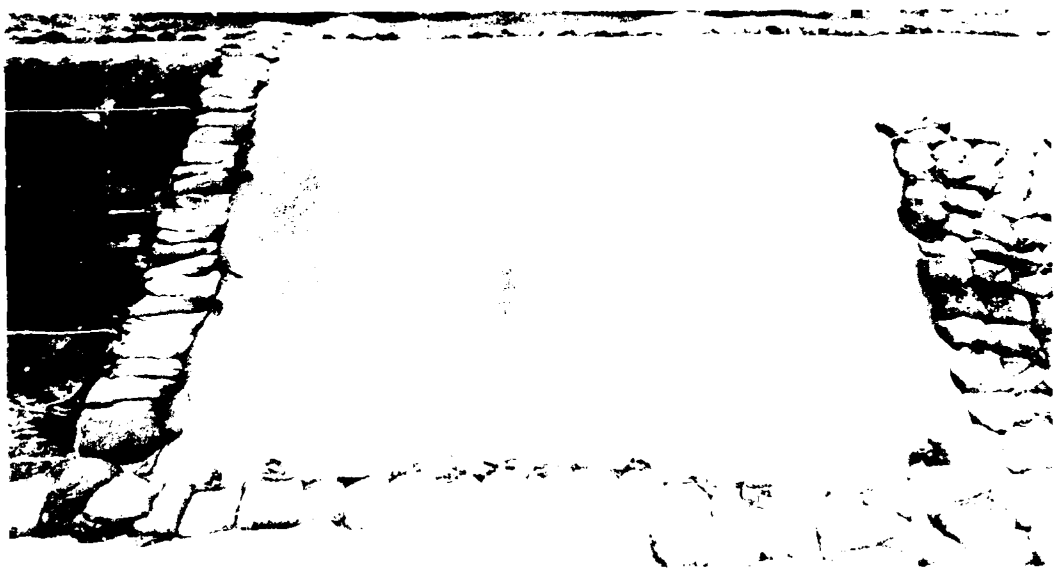


Photo 22. Item 2 — [illegible]

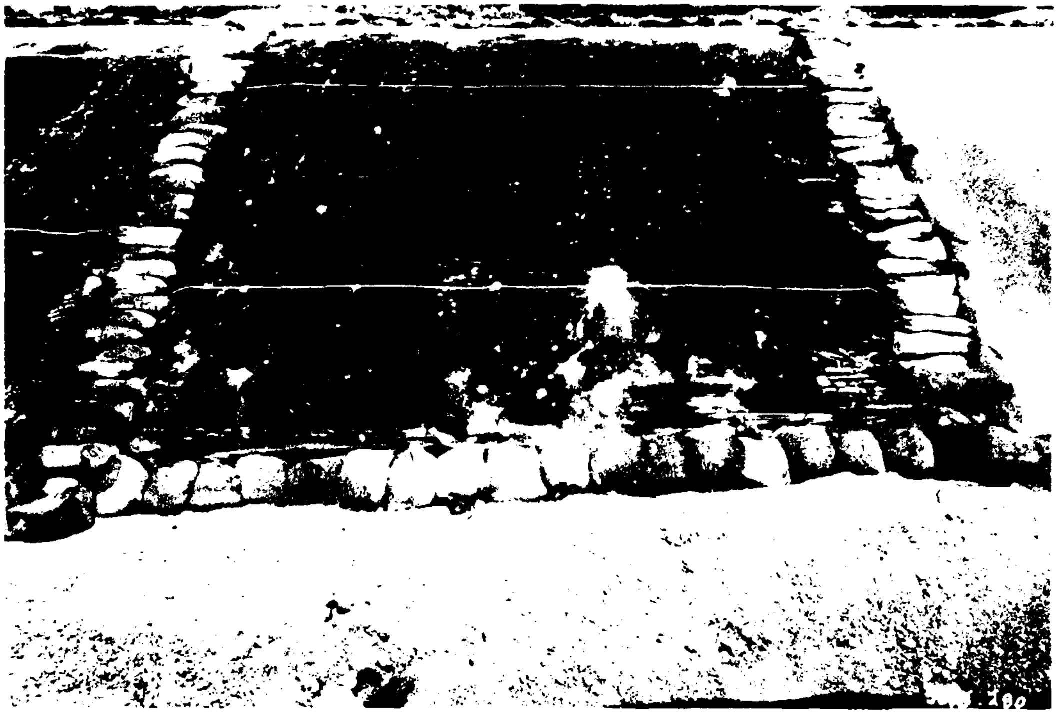


Photo 23. Item 3 - Hypalon 10×10 blanket

Photo 24. Item 4 - Hypalon 5×5 blanket

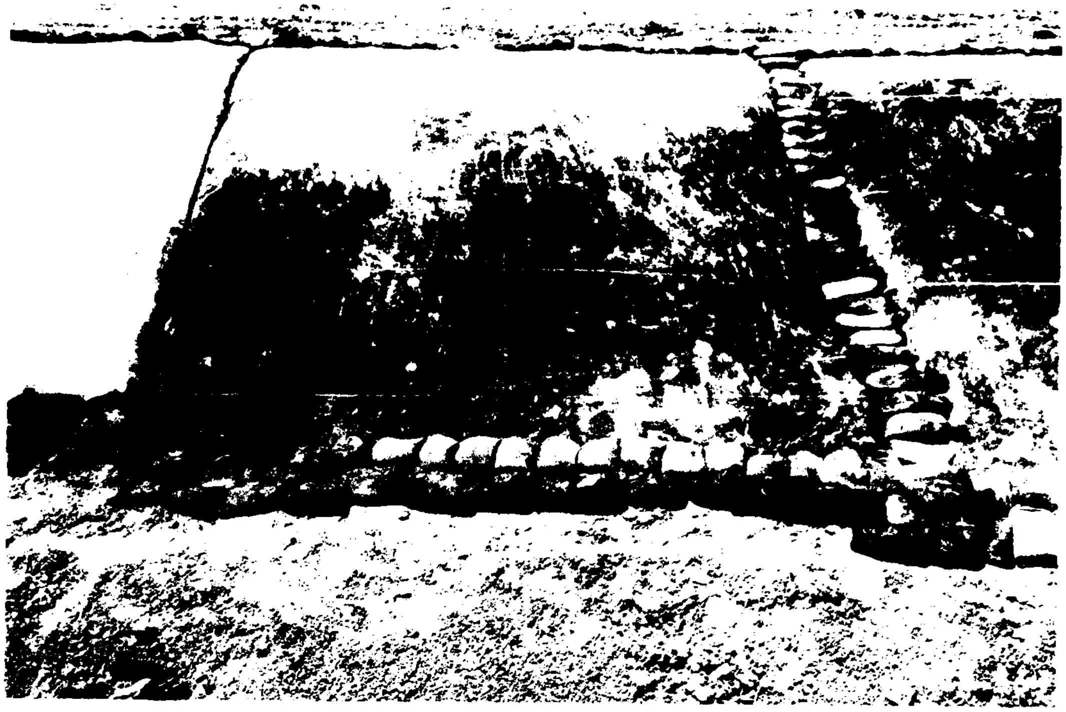


Photo 25. Item 5 - T16 blanket

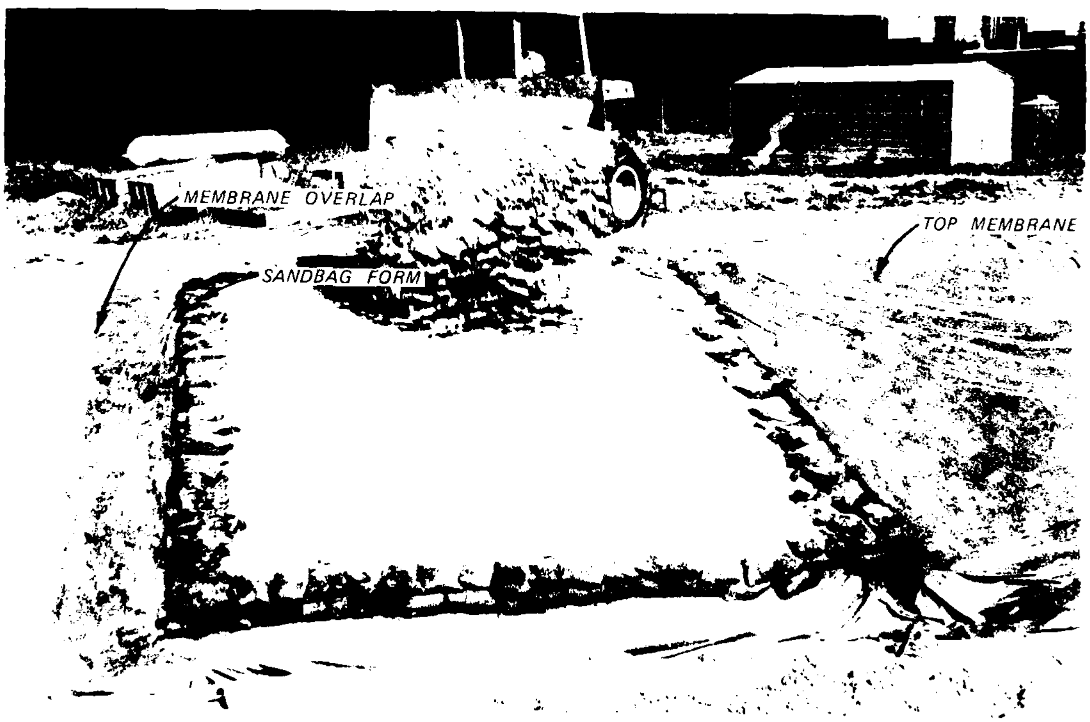


Photo 26. Sand backfill placed in area formed with sandbags

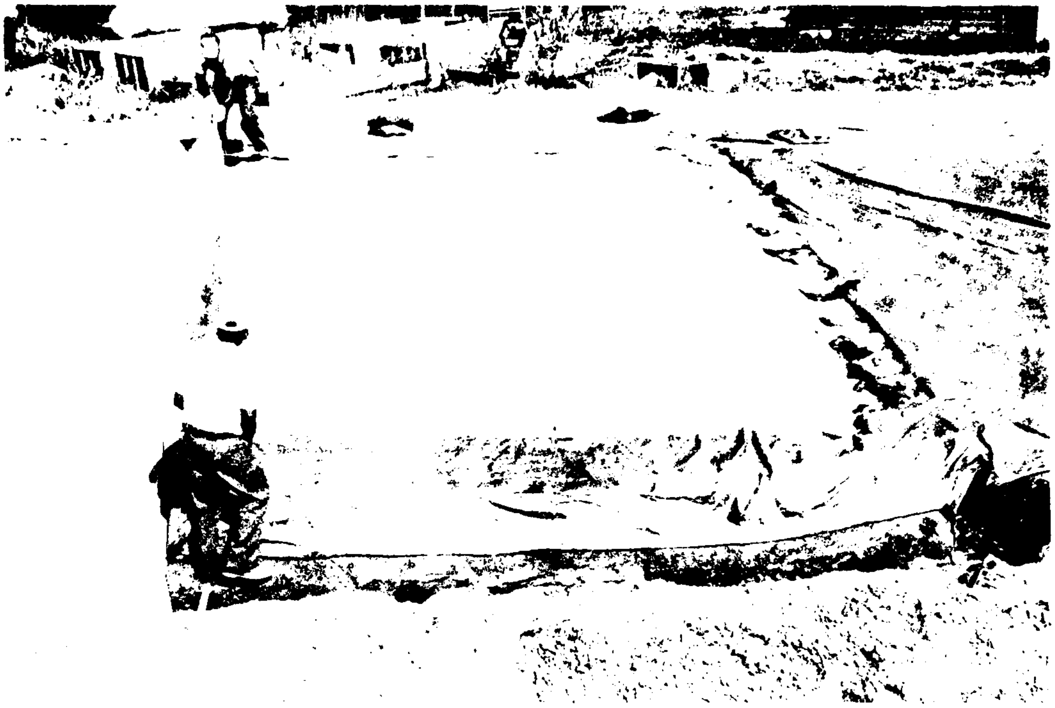


Photo 27. Membrane being overlapped at the sides of the sandbag form

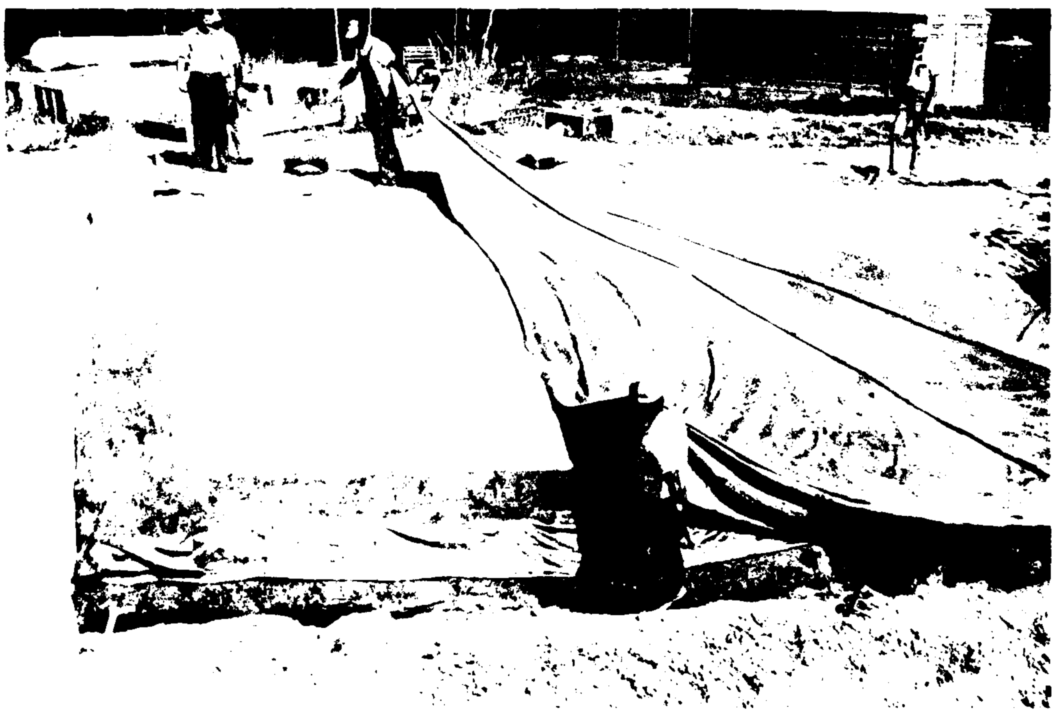


Photo 28. Top membrane being pulled over the sand-filled form

Photo 29. Anchoring of downstream edge of membrane

Photo 30. Item 6 - 115 MESL

Photo 31. Riprap being placed over Bidim C-34 filter fabric

Photo 32. Item 7 - Bidim C-34 fabric covered with riprap

Photo 33. Gurley current meter used to determine stream velocity and discharge data

Photo 34. View (looking downstream) of test area during high water

Photo 35. View (looking downstream) of test area after water had been on materials

Photo 36. View (looking downstream) of test area near the end of the monitoring period

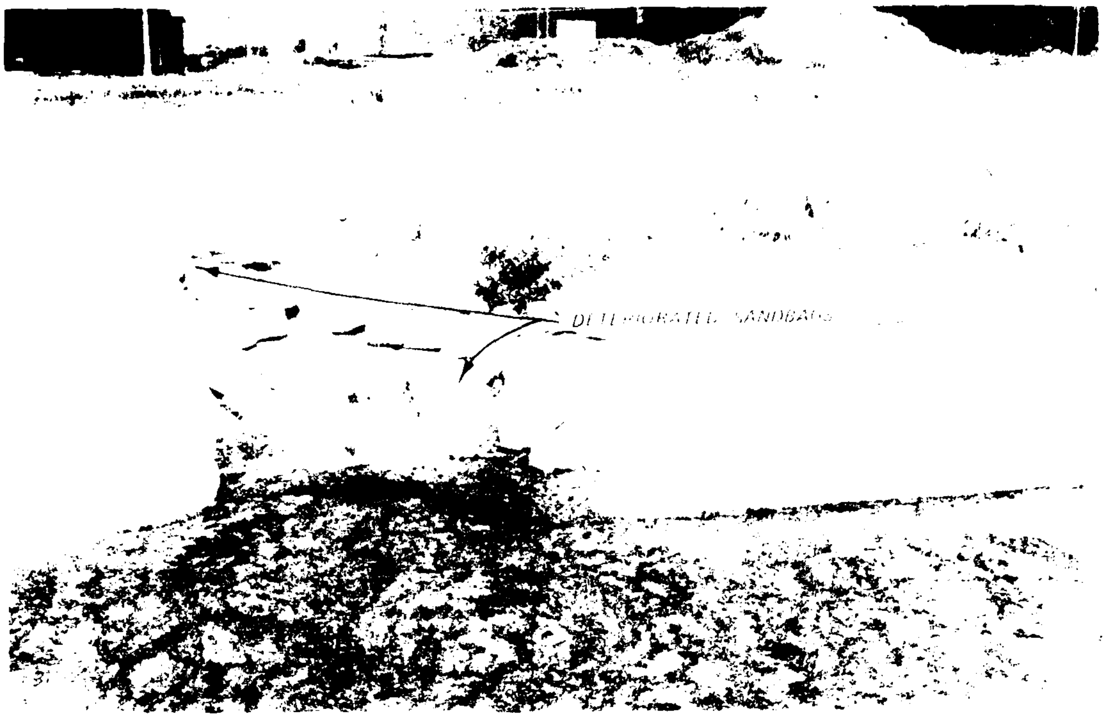


Photo 37. Typical view of deteriorated sandbags

Photo 38. View (looking upstream) of test area during high water level in creek (note membrane raised on Items 5 and 6 due to air entrapped beneath the membrane)

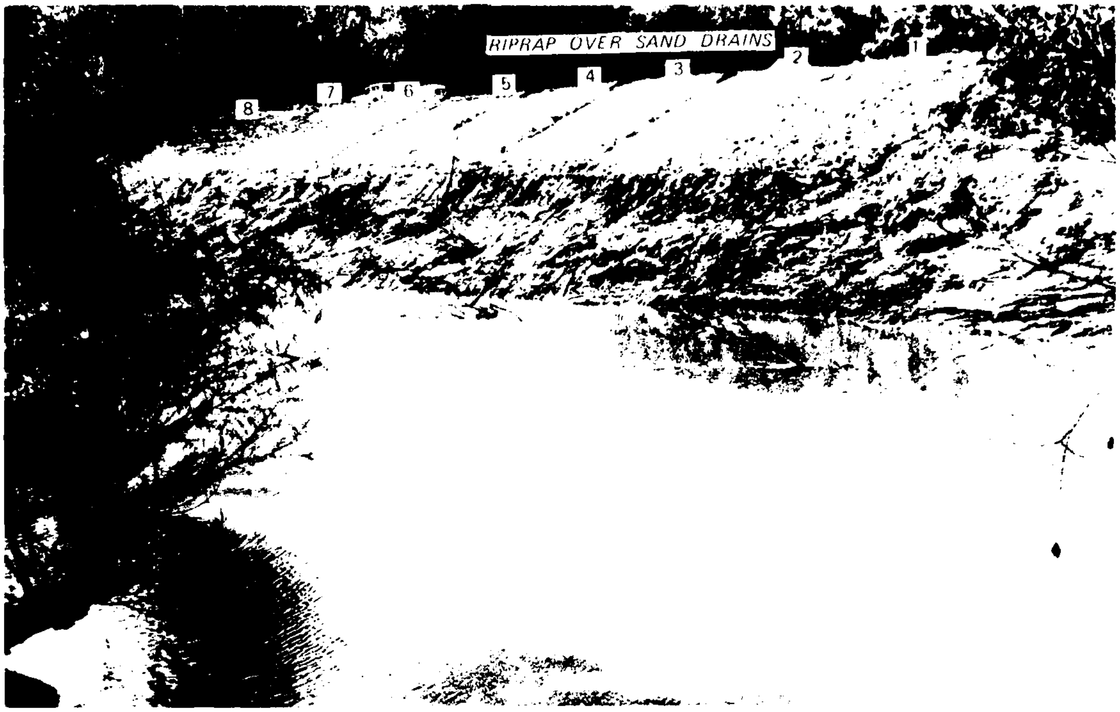


Photo 39. Downstream view of materials installed on bank of Big Black River

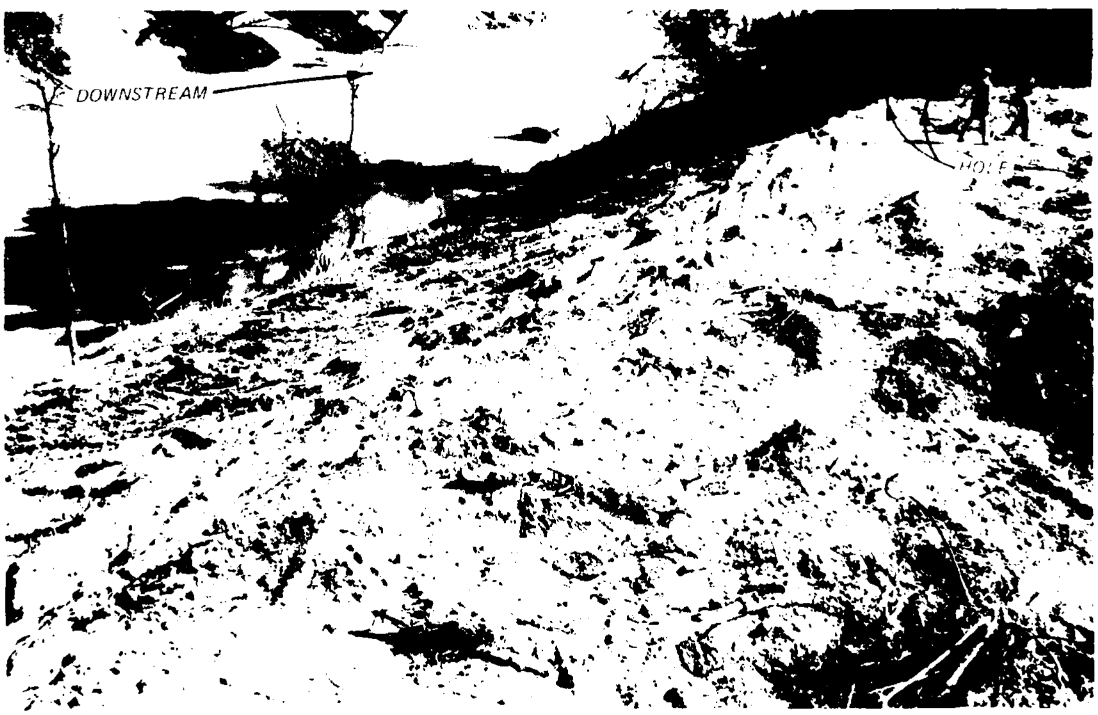


Photo 40. View of bank area with vegetation removed (note hole in bank). This area of bank selected for stepped MESL item (Item 8)

Photo 41. Shaped test site and excavation of bank for Item 1

Photo 42. Bidim C-38 fabric being placed in anchor ditches (perpendicular to streamflow)

Photo 43. Polyvinyl chloride perforated pipe wrapped with Bidim C-38 and placed on sand in the anchor ditch

Photo 44. Washed gravel placed over the polyvinyl chloride pipe at the toe of the ditch

Photo 45. Sand placed over the polyvinyl chloride pipe prior to being encapsulated with the Bidim fabric

Photo 46. Soil being placed in the anchor sand drain ditch prior to compacting

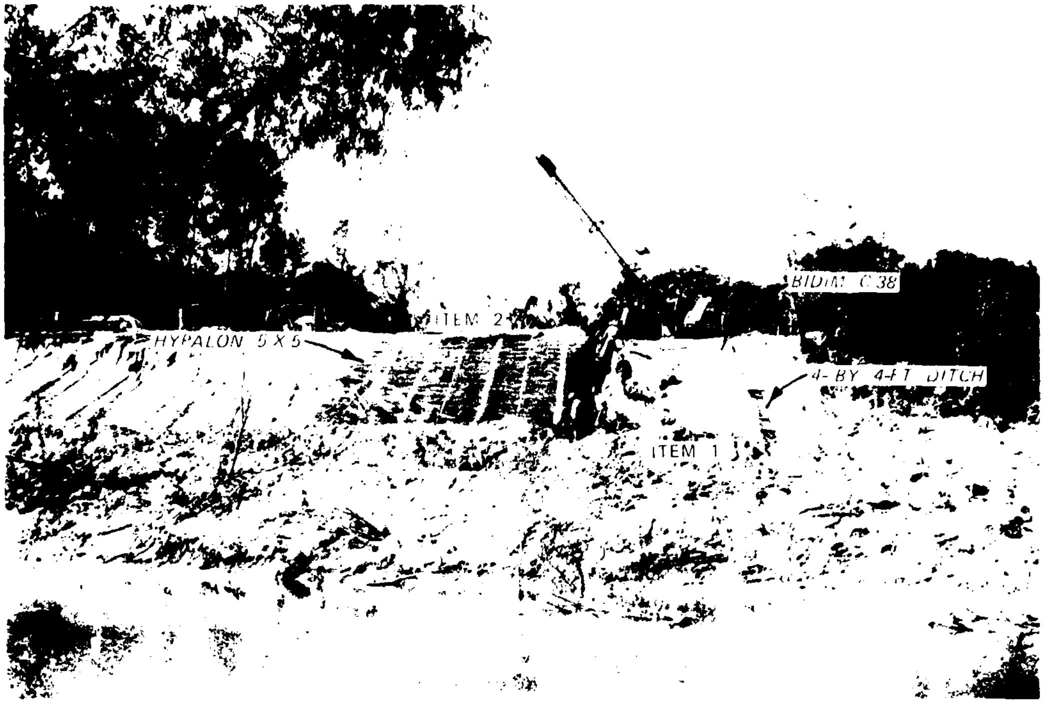


Photo 47. Bidim C-38 and membrane for Items 1 and 2 being placed

Photo 48. Placement of riprap on Item 1

Photo 49. Items 1 and 2 - riprap on Bidim C-38 filter fabric and Hypalon 5×5 membrane

Photo 50. Items 3 and 4, Hypalon 10×10 and T15 blankets

Photo 51. Items 5 and 6 - T16 membrane blanket and T15 MESL

Photo 52. Form constructed of bagged concrete mix on MESL Item 6; bags being sprayed with water to cure mix in bags

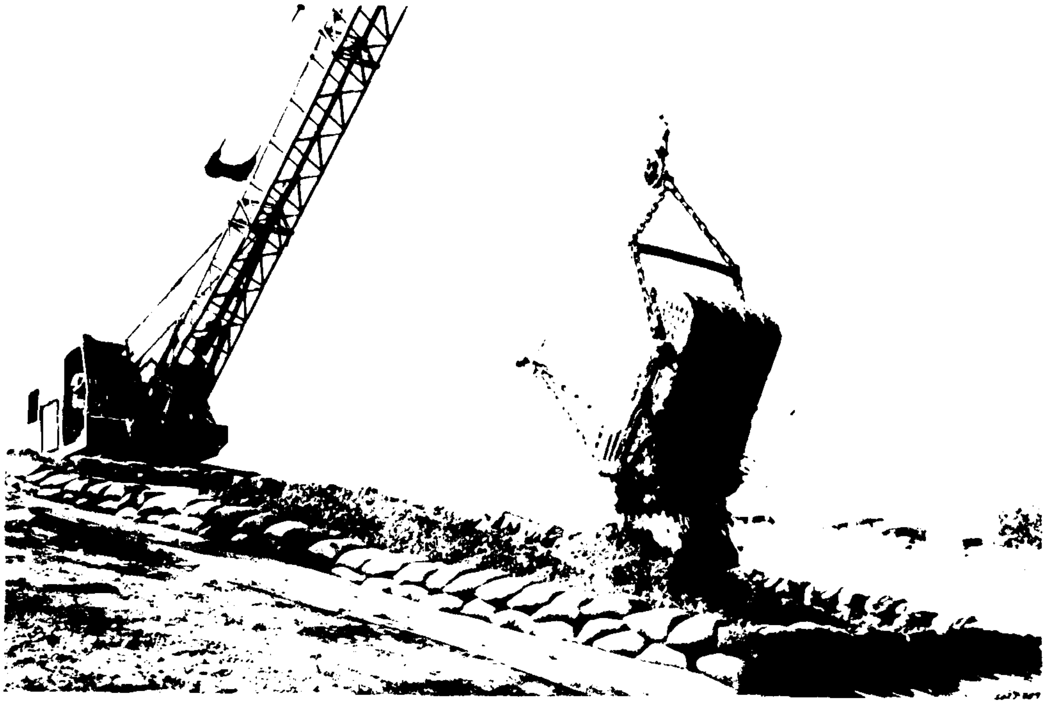


Photo 53. Backfill material being placed in form of MESL Item 6

Photo 54. Bank area for stepped MESL materials (Item 8) (note that soil had previously washed from beneath the tree roots)

Photo 55. First step of stepped MESL Item 8

Photo 56. Placement of top sheet of membrane on the first step of Item 8

Photo 57. Items 7 and 8 - Riprap on Bidim C-38 filter fabric and T15 membrane stepped section

Photo 58. Area just below test Item 8 (note soil around tree roots and bank area had eroded prior to installation of test materials)

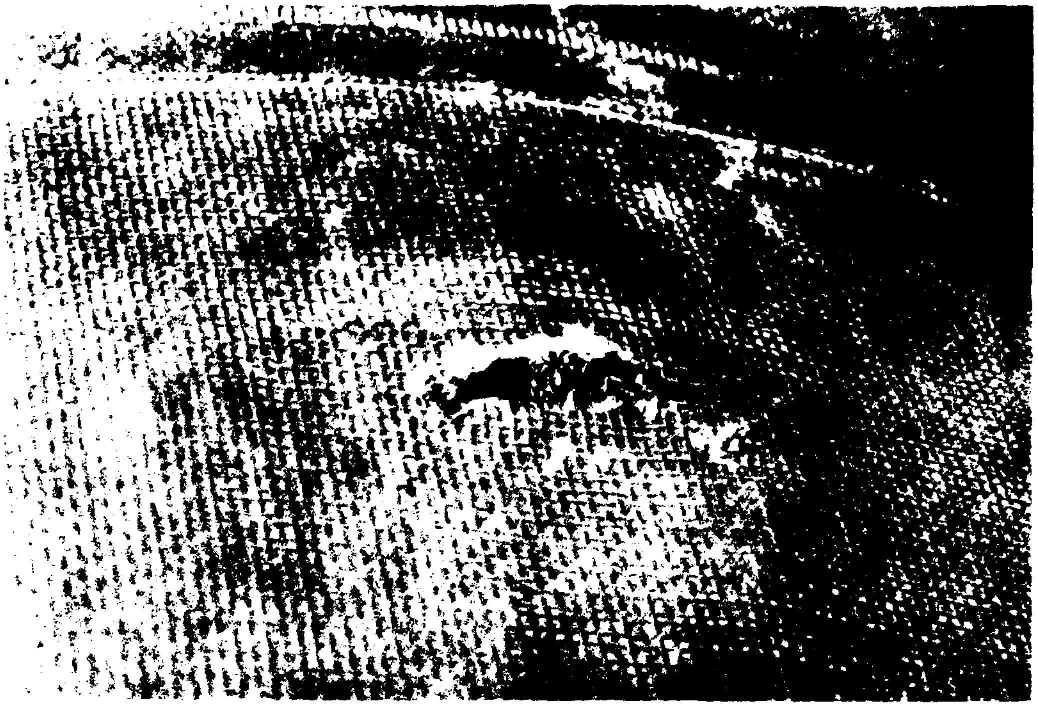


Photo 59. Membrane torn by riprap being dropped

Photo 60. Patch on membrane where it had been damaged by riprap

Photo 61. Water velocities and discharge data being taken

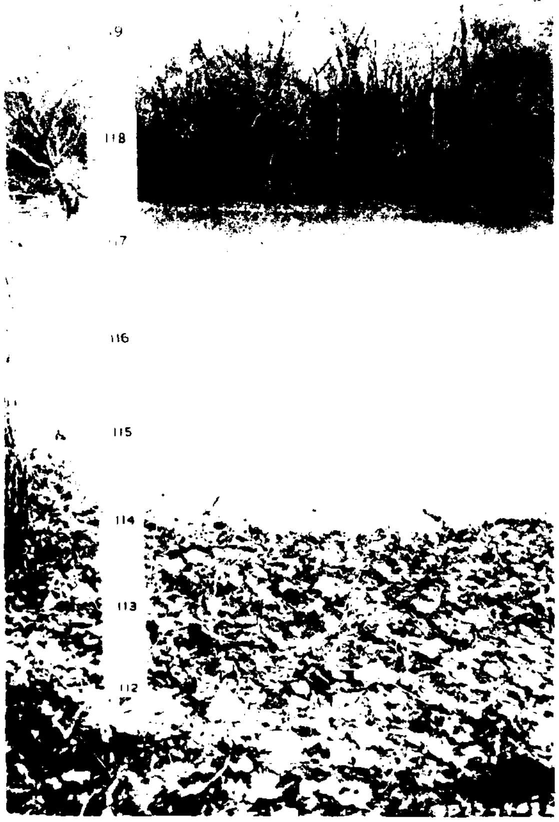


Photo 62. Staff gages at Big Black River for determining river stages

Photo 63. Ground water level data being taken from piezometer, P_1, near the riverbank

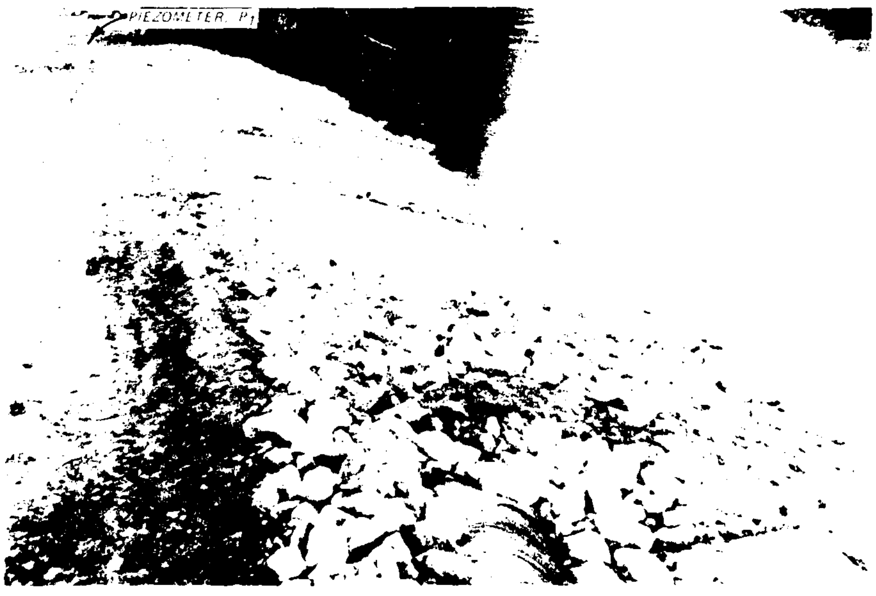


Photo 64. View looking upriver of test area as the water level rose in the river during mid-November 1979

Photo 65. View looking downriver at water at top bank and covering test area

Photo 66. View looking downriver of test items (note large deposits of silt left on materials as water level dropped)

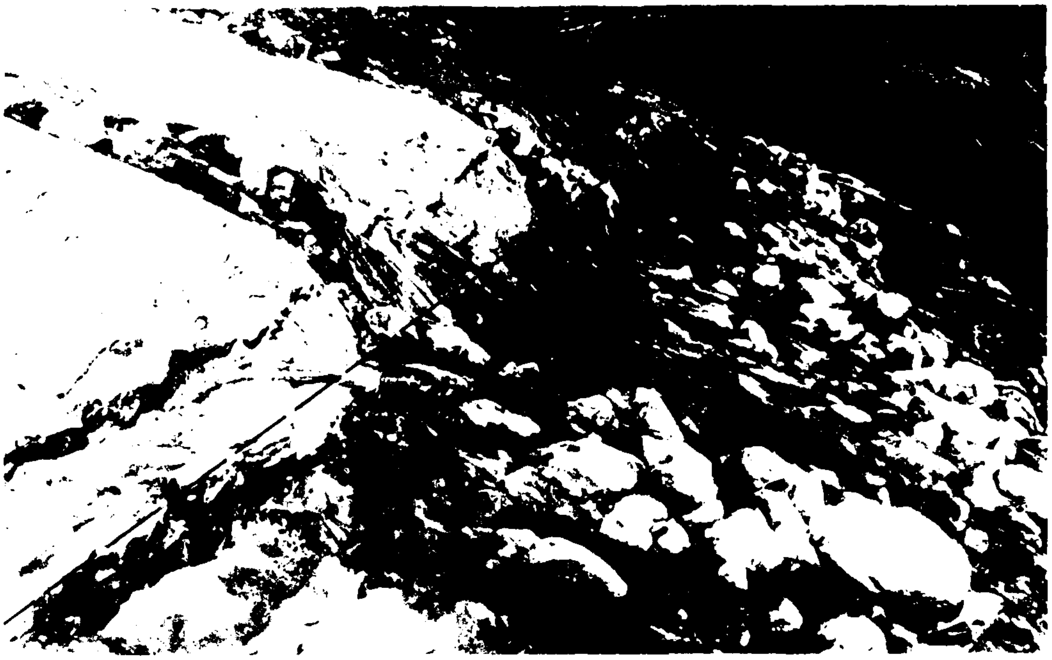


Photo 67. View (looking upriver) of test bank where shifting and sliding had occurred at the toe anchor ditch after a sudden drop in the water level of the river

Photo 68. View (looking upriver) of bank area adjacent to the test area where the bank had slid and shifted as a result of a sudden drop in the water level of the river

Photo 69. View (looking downriver) of bank area downstream of the test area where shifting and sliding had occurred

Photo 70. View (looking upriver) of test area covered by 2 ft of water, 31 Mar 1980

Photo 71. View of top bank adjacent to Items 5 and 6 of damage caused by water flowing over top bank during high-water level in late March and early April

Photo 72. View (looking downriver) of test area with water covering half of the bank, 9 May 1980

Photo 73. View (looking downriver) of test area after water level had fallen below the toe of the test materials, 12 May 1980

Photo 74. View (looking upriver) of damaged test items after a sudden drop in the water level, 12 May 1980

Photo 75. View (looking upriver) at toe of materials (note damage to test items and failed bank area)

Photo 76. Lower edge of Item 8 where bank failed and shifted after the rapid drop in water level, 12 May 1980

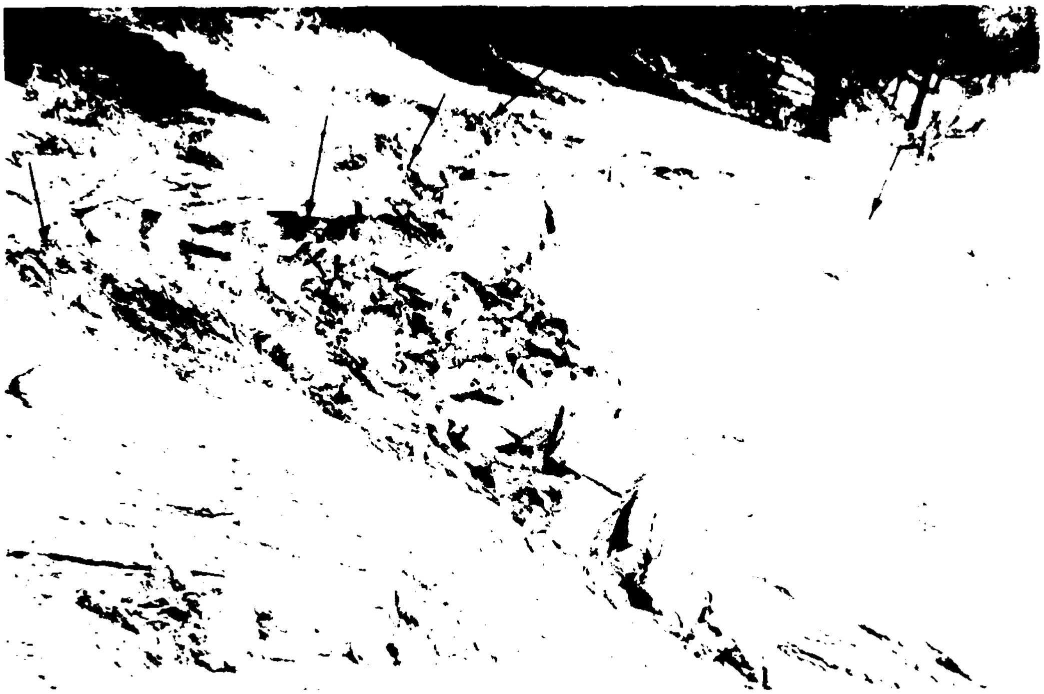


Photo 77. View (looking upriver) of bank adjacent to the upriver edge of the test area which had failed due to the rapid drop in water level, 12 May 1980

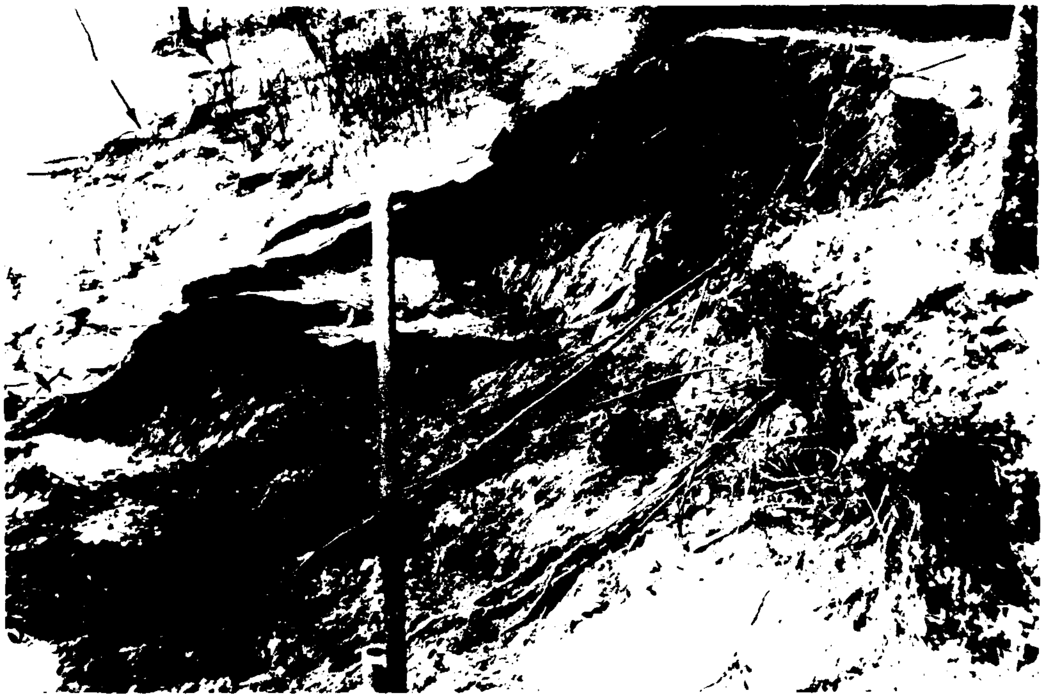


Photo 78. View (looking downriver) of bank adjacent to the downriver edge of the test area which had failed due to the rapid drop in water level, 12 May 1980

Photo 79. Upstream view (from river) of test area, July 1980

Photo 80. Close-up of Items 1 and 2, July 1980

Photo 81. Close-up of Items 3 and 4, July 1980

Photo 82. Close-up of Items 5 and 6, July 1980

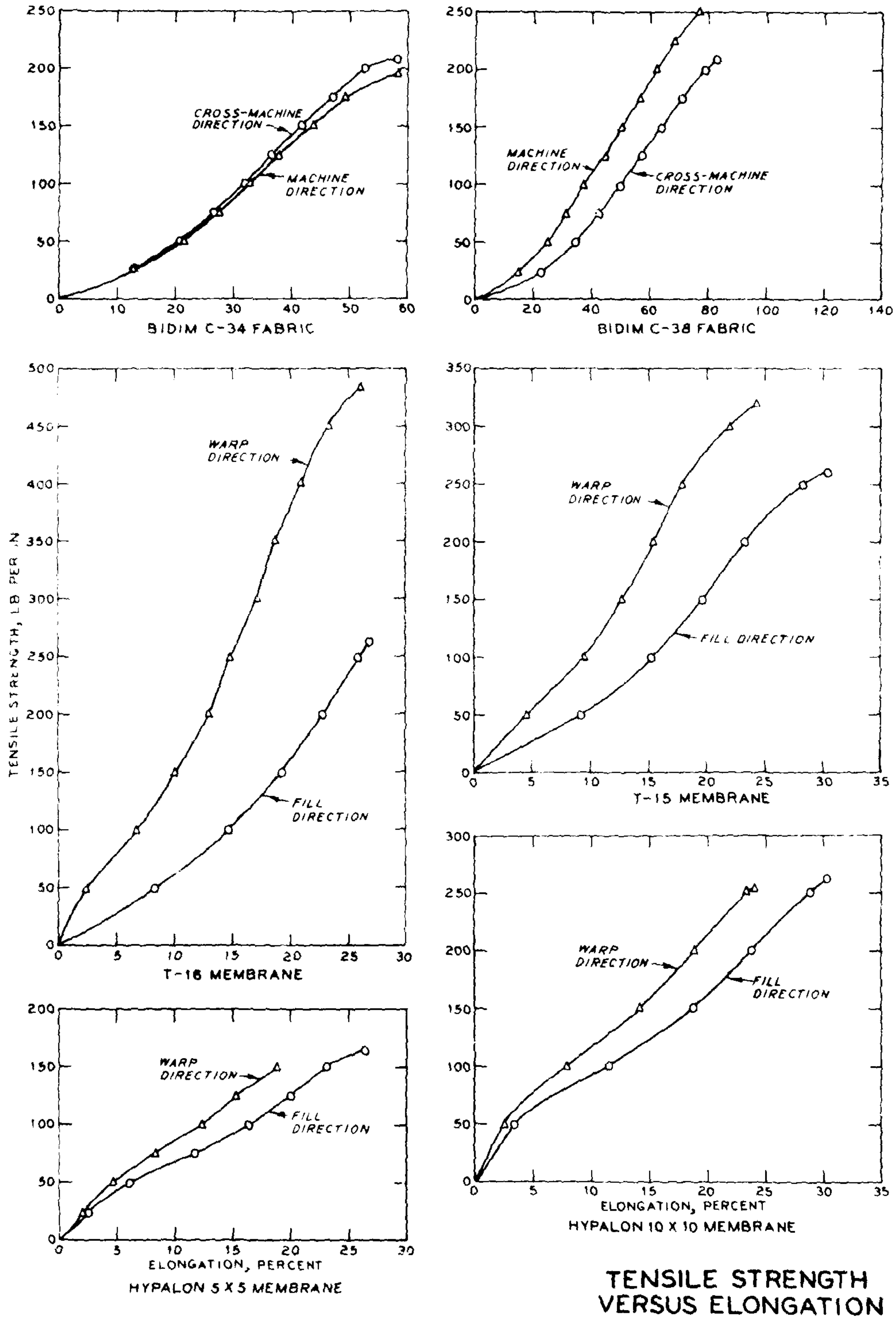
Photo 83. Close-up of Items 7 and 8, July 1980

Photo 84. View of riverbank downstream of test area where sliding and sluffing occurred as a result of the sudden drops in the water level of the river

Photo 85. View of trees along lower bank and in river where sliding and sluffing of the bank occurred

Photo 86. View of trees in river where sliding and sluffing of the bank occurred

Photo 87. View of bridge pier downstream of area where sliding and sluffing of the bank and trees occurred during sudden drops in the water level of the river



TENSILE STRENGTH
VERSUS ELONGATION

GRAB TEST METHOD

PLATE 1

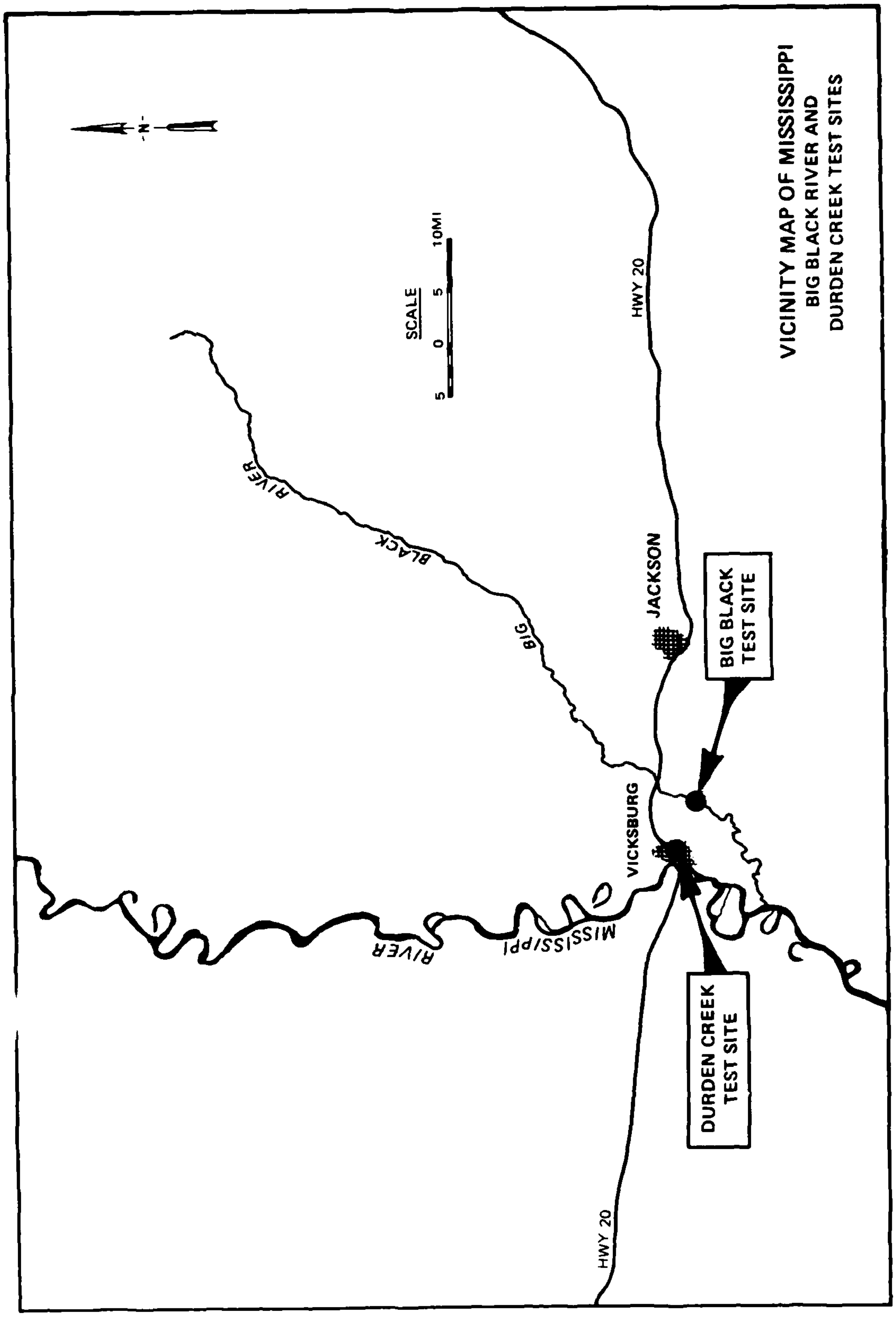

VICINITY MAP OF MISSISSIPPI
BIG BLACK RIVER AND
DURDEN CREEK TEST SITES
SCALE
5 0 5 10MI
N
HWY 20
JACKSON
BIG BLACK RIVER
BIG BLACK
TEST SITE
VICKSBURG
MISSISSIPPI RIVER
DURDEN CREEK
TEST SITE
HWY 20

PLATE 2

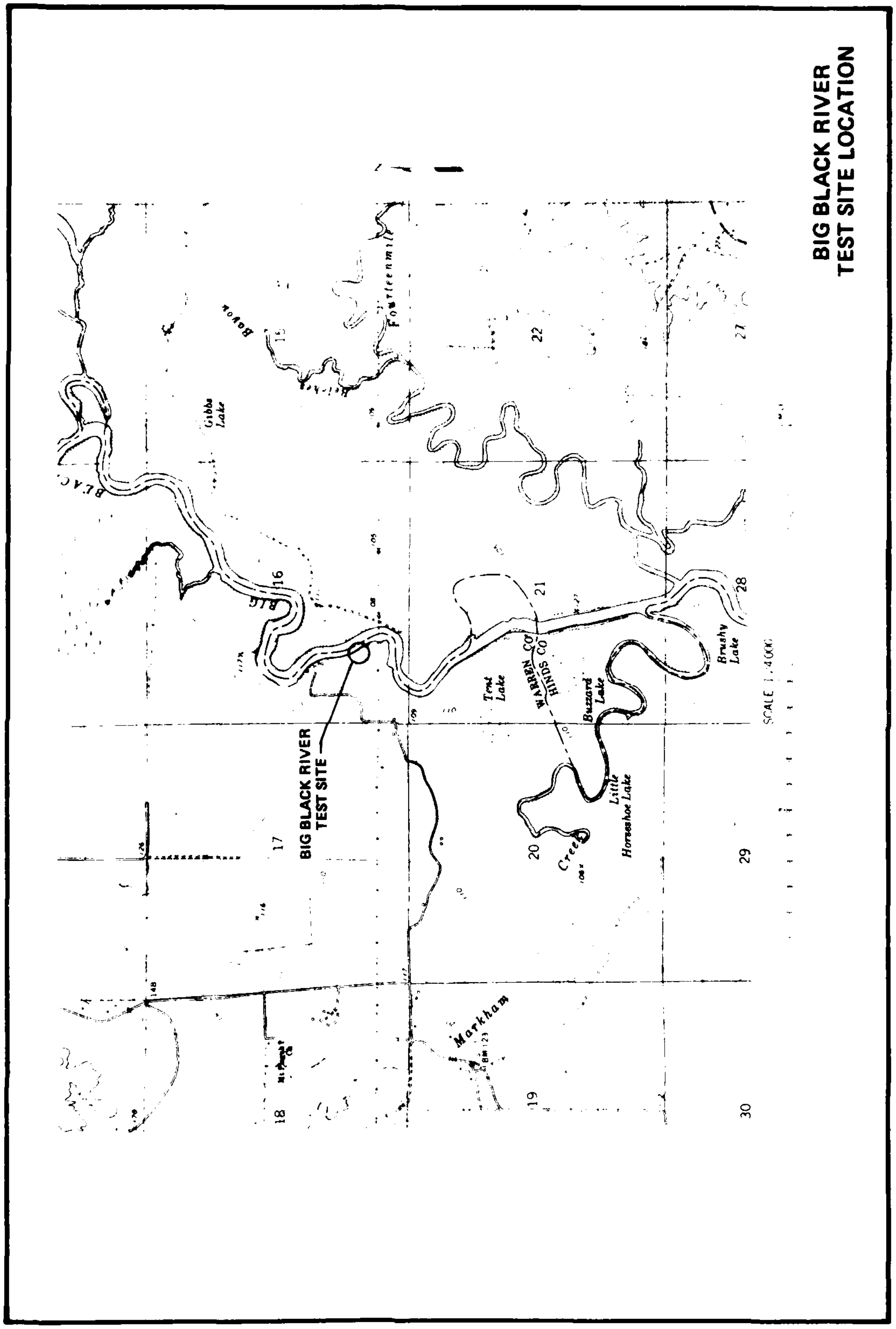
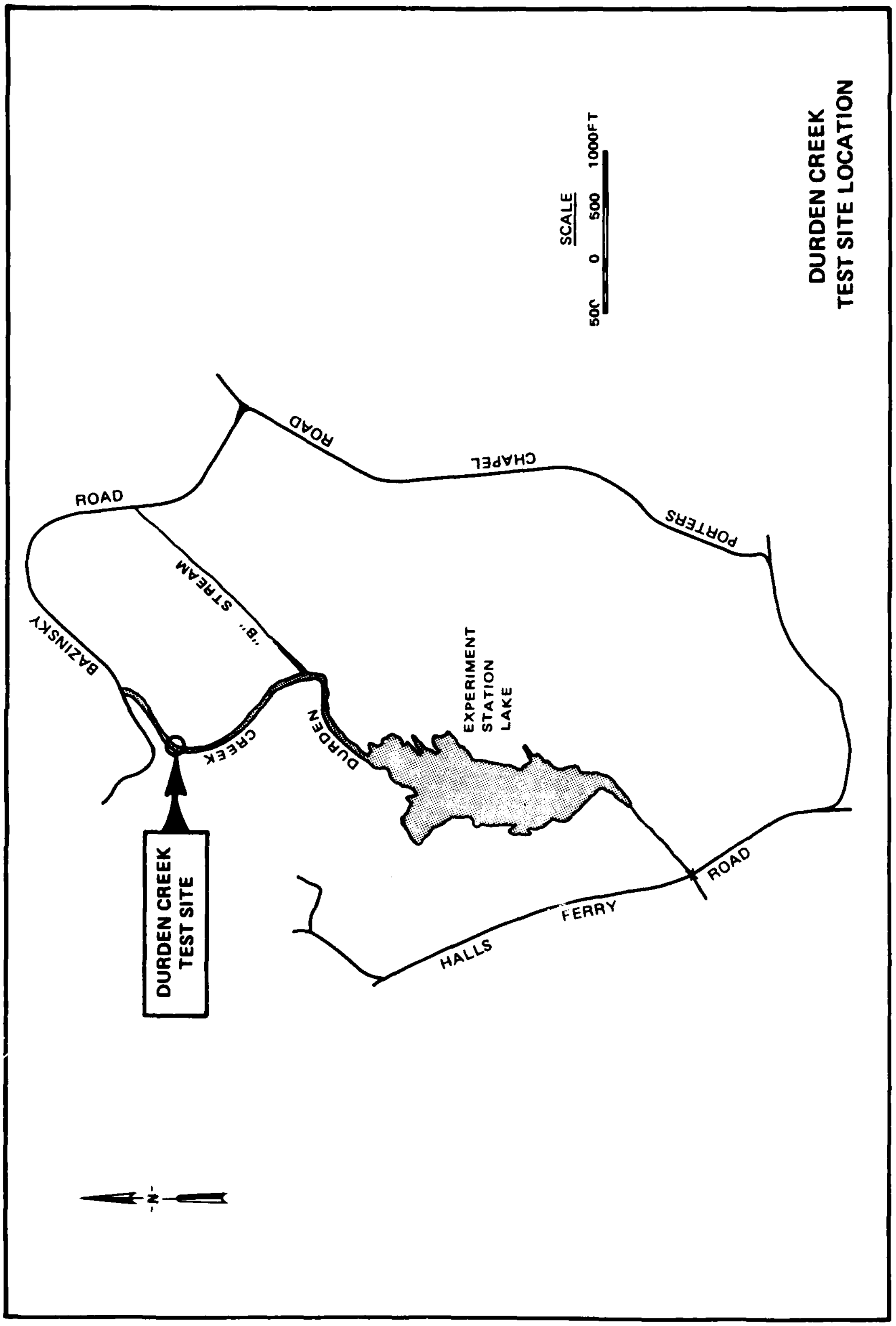
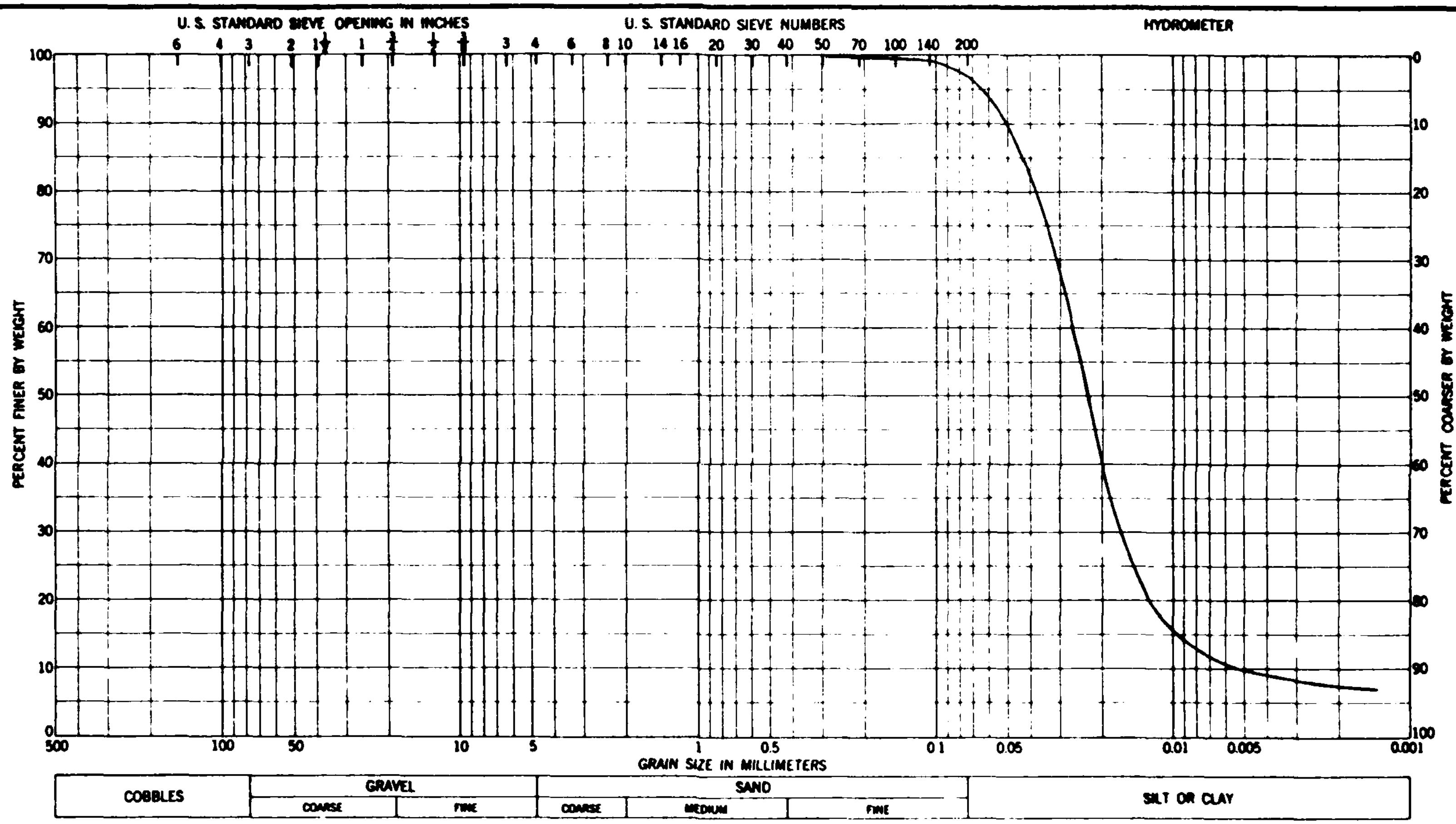

BIG BLACK RIVER
TEST SITE LOCATION
BIG BLACK RIVER
TEST SITE
Gibbs Lake
Bayou
Fourteenmile
Trest Lake
WARREN CO
HINDS CO
Buzzard Lake
Brushy Lake
Little Horseshoe Lake
Creek
Markham
16
17
18
19
20
21
22
28
29
30

PLATE 3



DURDEN CREEK
TEST SITE LOCATION
SCALE
500 0 500 1000FT
N
ROAD
CHAPEL
PORTERS
ROAD
BAZINSKY
"B" STREAM
EXPERIMENT
STATION
LAKE
DURDEN
CREEK
HALLS
FERRY
ROAD
DURDEN CREEK
TEST SITE

PLATE 4



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
		Silt (ML)		35	27	8

Project: Streambank Erosion Study

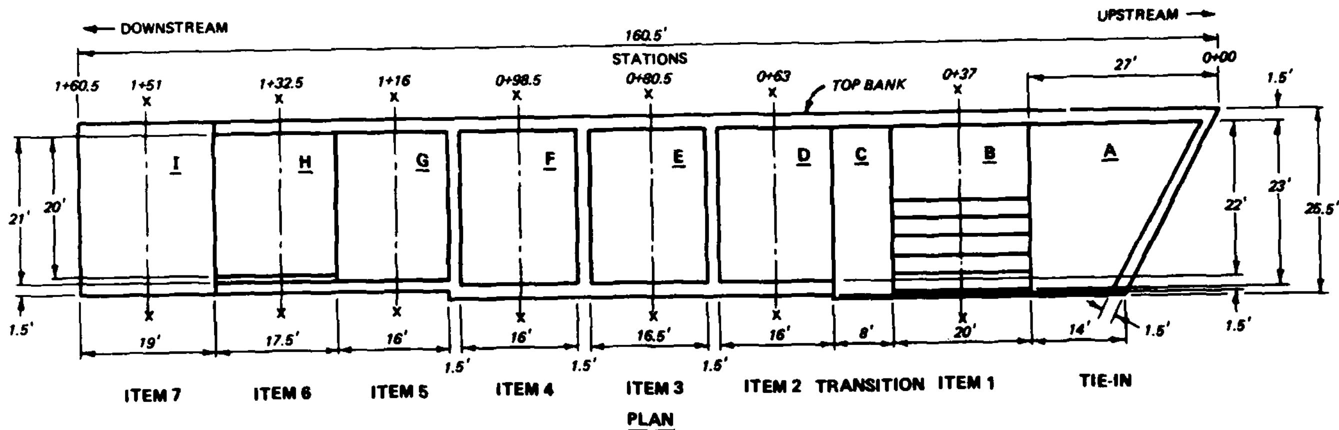
Area: [illegible]

Boring No

Date

GRADATION CURVES

ENG FORM 1 MAY 63 2087



LEGEND

A. T-15 MEMBRANE TIE-IN TO TEST ITEMS (SEE SHEET 2)

B. ITEM 1 – STEPPED T-15 MEMBRANE MESL (SEE SHEET 3)

C. T-15 MEMBRANE AND SAND BAG TRANSITION (SEE SHEET 4)

D. ITEM 2 – T-15 MEMBRANE (SEE SHEET 4)

E. ITEM 3 – HYPALON 10 x 10 MEMBRANE (SEE SHEET 5)

F. ITEM 4 – HYPALON 5 x 5 MEMBRANE (SEE SHEET 5)

G. ITEM 5 – T-16 MEMBRANE (SEE SHEET 6)

H. ITEM 6 – T-15 MEMBRANE MESL (SEE SHEET 6)

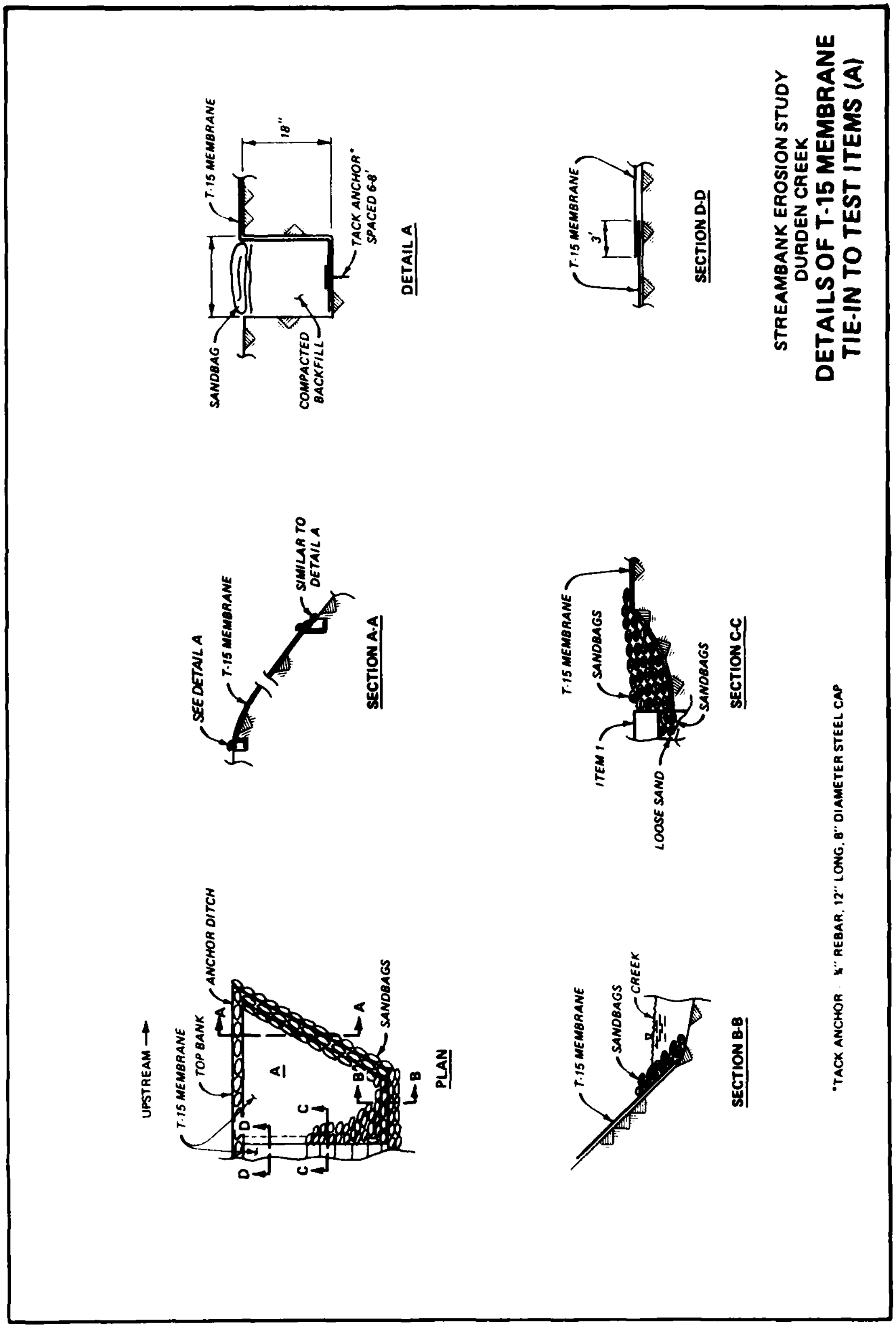
I. ITEM 7 – RIPRAP ON BIDIM C-34 FABRIC (SEE SHEET 7)

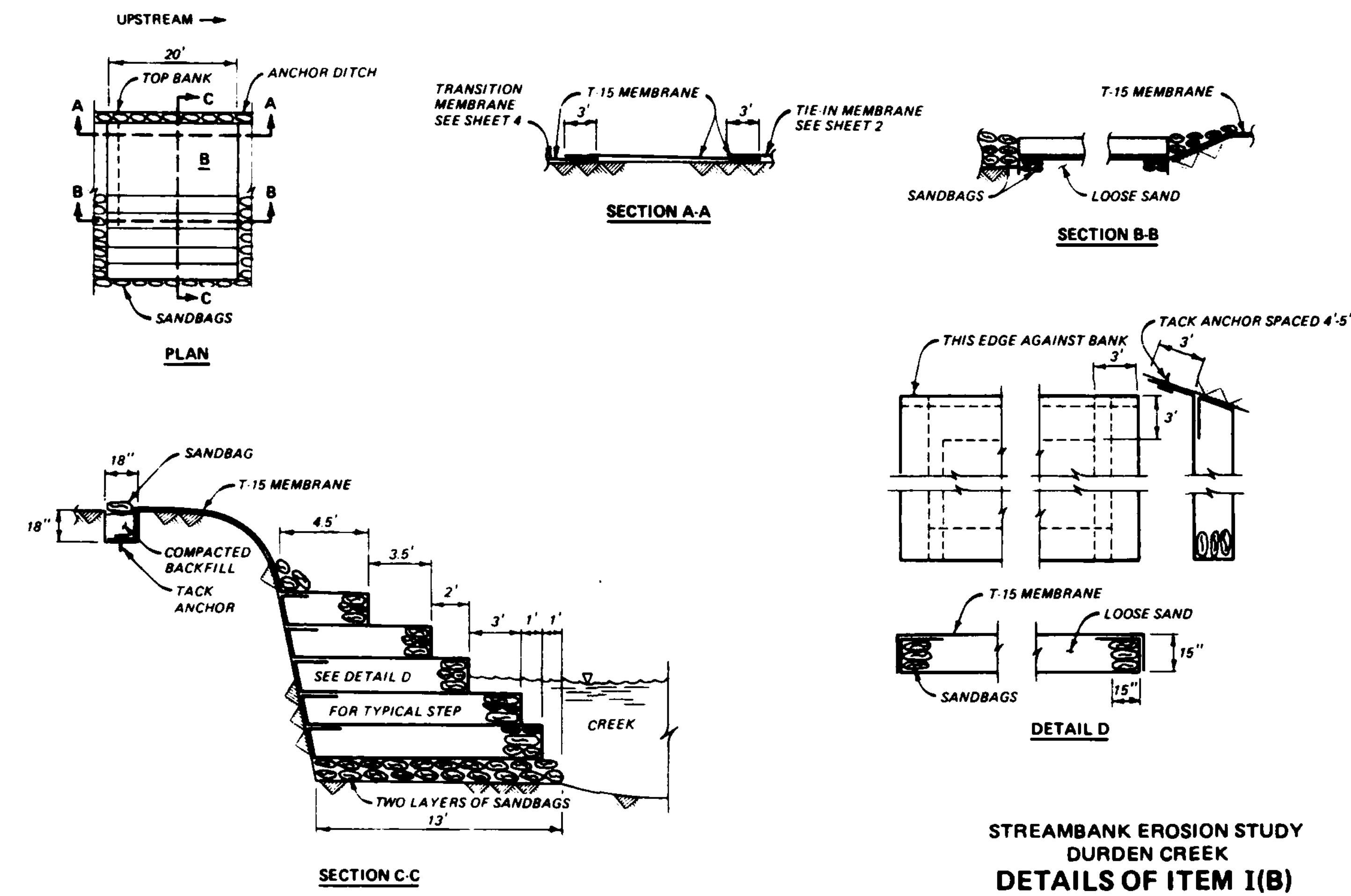
X—·—X CROSS-SECTION DATA POINTS

NOTE: NO SCALE ON ANY OF THE SHEETS

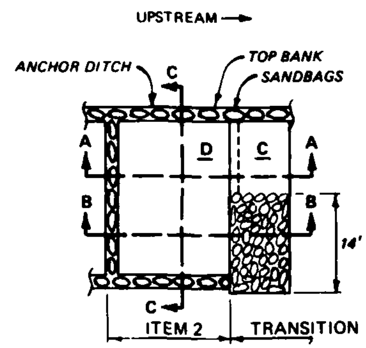
STREAMBANK EROSION STUDY
DURDEN CREEK
TEST SECTION LAYOUT

PLATE 6 (SHEET 1 OF 7)

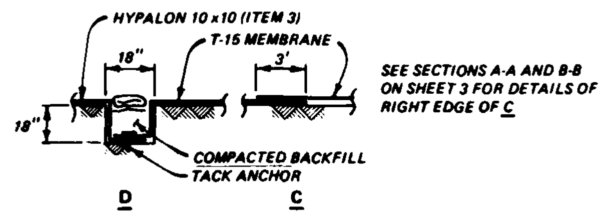

STREAMBANK EROSION STUDY
DURDEN CREEK
DETAILS OF T-15 MEMBRANE TIE-IN TO TEST ITEMS (A)
UPSTREAM
T-15 MEMBRANE
TOP BANK
ANCHOR DITCH
SANDBAGS
PLAN
SEE DETAIL A
T-15 MEMBRANE
SIMILAR TO DETAIL A
SECTION A-A
SANDBAG
COMPACTED BACKFILL
T-15 MEMBRANE
18"
TACK ANCHOR* SPACED 6-8'
DETAIL A
T-15 MEMBRANE
SANDBAGS
CREEK
SECTION B-B
T-15 MEMBRANE
SANDBAGS
ITEM 1
LOOSE SAND
SANDBAGS
SECTION C-C
T-15 MEMBRANE
3'
SECTION D-D
*TACK ANCHOR - ¼" REBAR, 12" LONG, 8" DIAMETER STEEL CAP



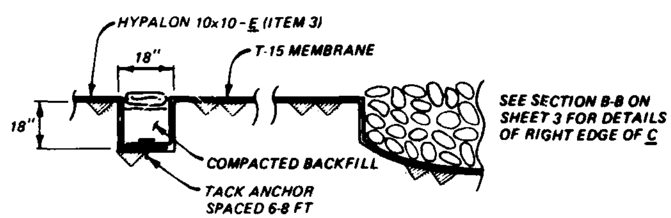
STREAMBANK EROSION STUDY
DURDEN CREEK
DETAILS OF ITEM I(B)
STEPPED T-15 MEMBRANE MESL



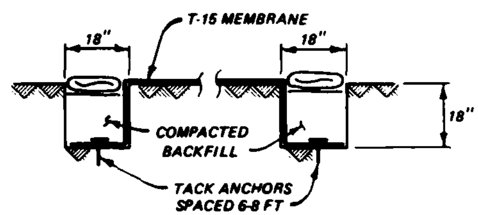
PLAN



SECTION A-A



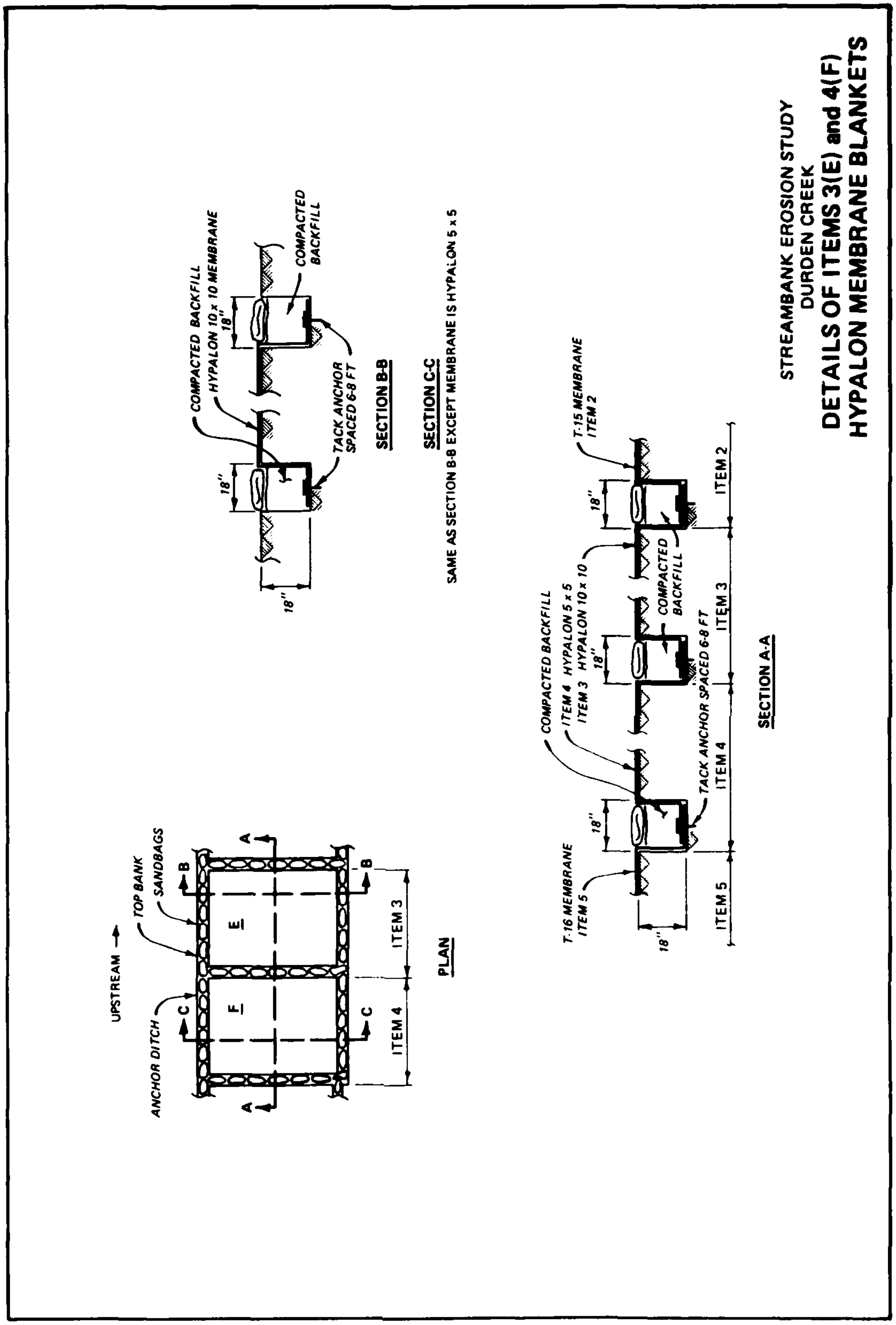
SECTION B-B

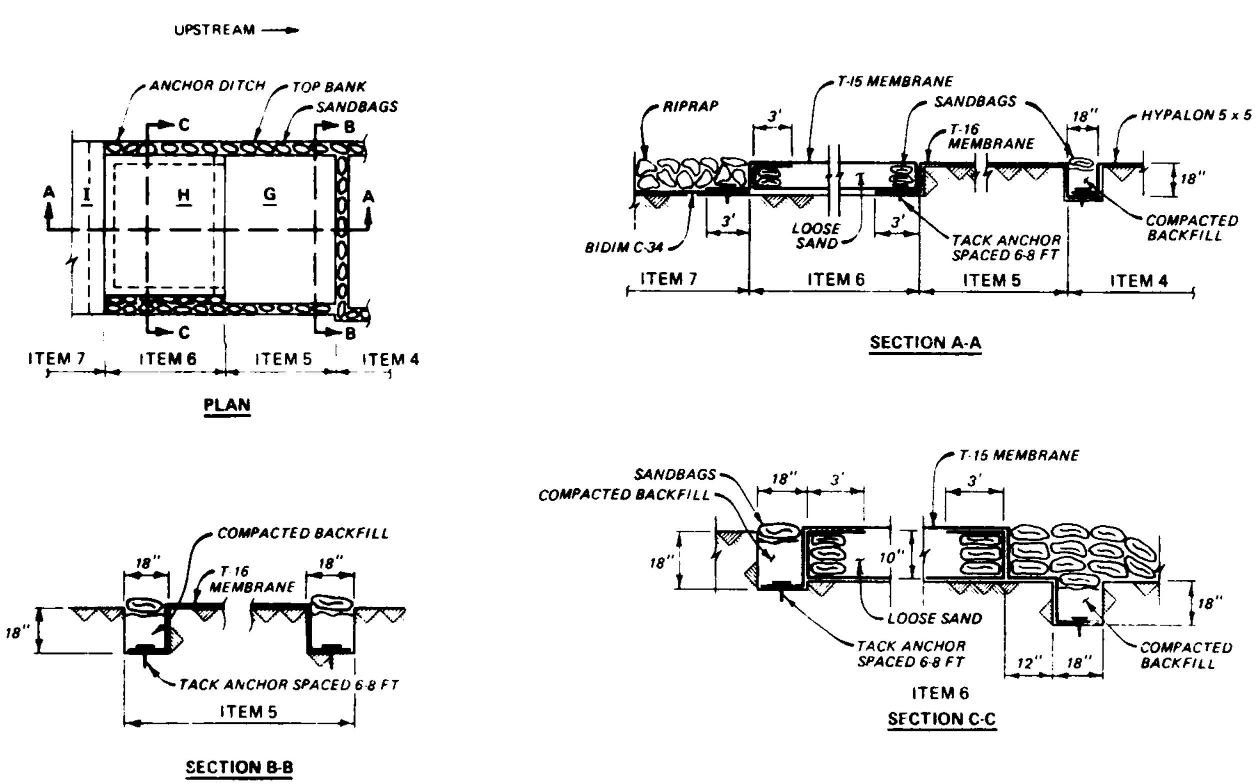


SECTION C-C

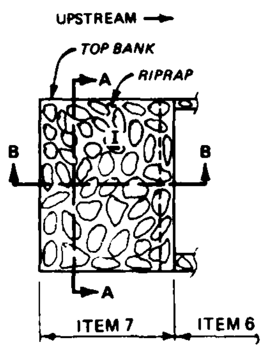
STREAMBANK EROSION STUDY
DURDEN CREEK

DETAILS OF T-15-SANDBAG TRANSITION AND ITEM 2(D) T-15 MEMBRANE BLANKET

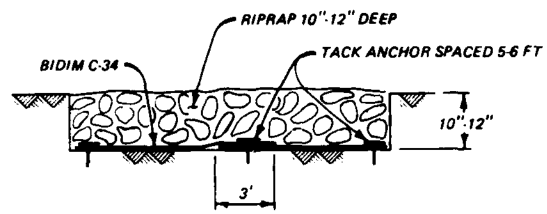

STREAMBANK EROSION STUDY
DURDEN CREEK
DETAILS OF ITEMS 3(E) and 4(F)
HYPALON MEMBRANE BLANKETS
UPSTREAM
ANCHOR DITCH
TOP BANK
SANDBAGS
E
F
ITEM 3
ITEM 4
PLAN
COMPACTED BACKFILL
HYPALON 10 x 10 MEMBRANE
COMPACTED BACKFILL
TACK ANCHOR SPACED 6-8 FT
18"
SECTION B-B
SECTION C-C
SAME AS SECTION B-B EXCEPT MEMBRANE IS HYPALON 5 x 5
T-16 MEMBRANE ITEM 5
COMPACTED BACKFILL
ITEM 4 HYPALON 5 x 5
ITEM 3 HYPALON 10 x 10
TACK ANCHOR SPACED 6-8 FT
COMPACTED BACKFILL
T-15 MEMBRANE ITEM 2
ITEM 5
ITEM 4
ITEM 3
ITEM 2
SECTION A-A



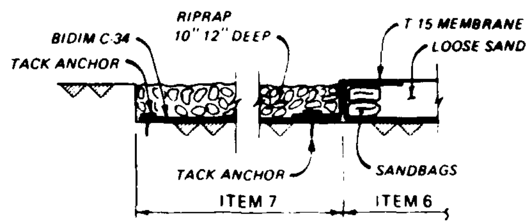
STREAMBANK EROSION STUDY
DURDEN CREEK
DETAILS OF ITEMS 5(G) and 6(H)



PLAN



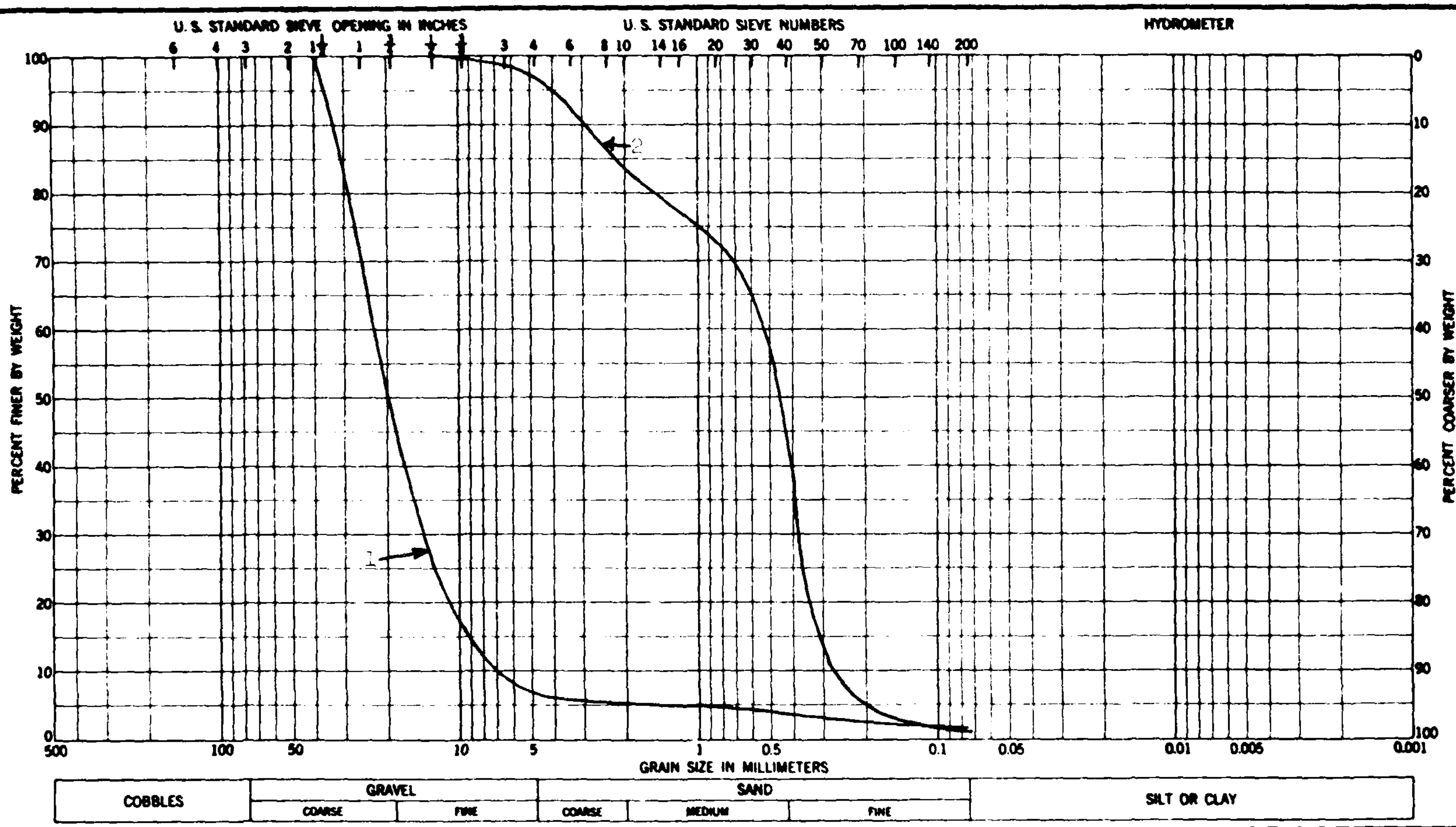
SECTION A-A



SECTION B-B

STREAMBANK EROSION STUDY
DURDEN CREEK
DETAILS OF ITEM 7(I)
RIPRAP ON BIDIM C-34

PLATE 6 (SHEET 7 OF 7)



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
1		Washed Gravel (GP)		NP		
2		Sand (SP) with Trace Gravel				

Project Streambank Erosion Study

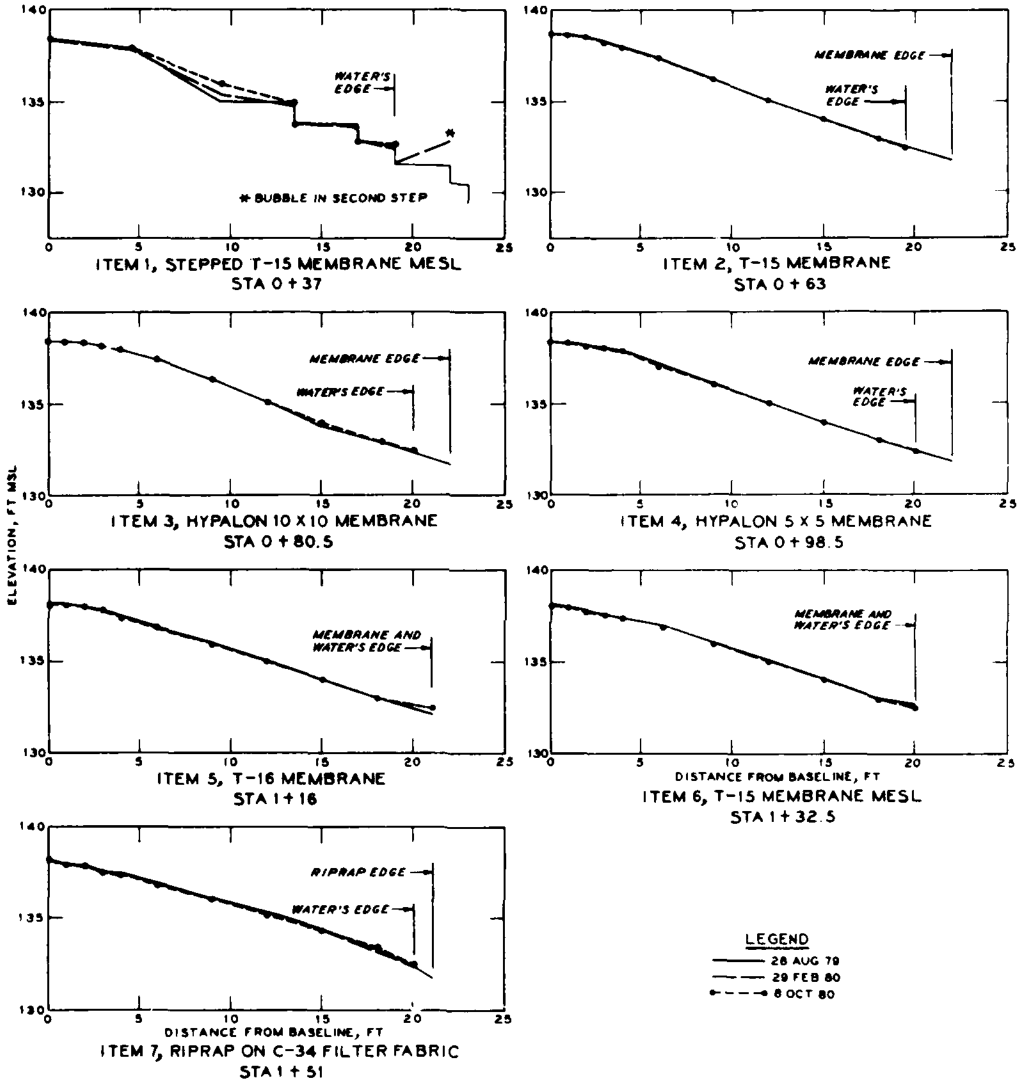
Area Durden Creek & Big Black River

Boring No.

Date

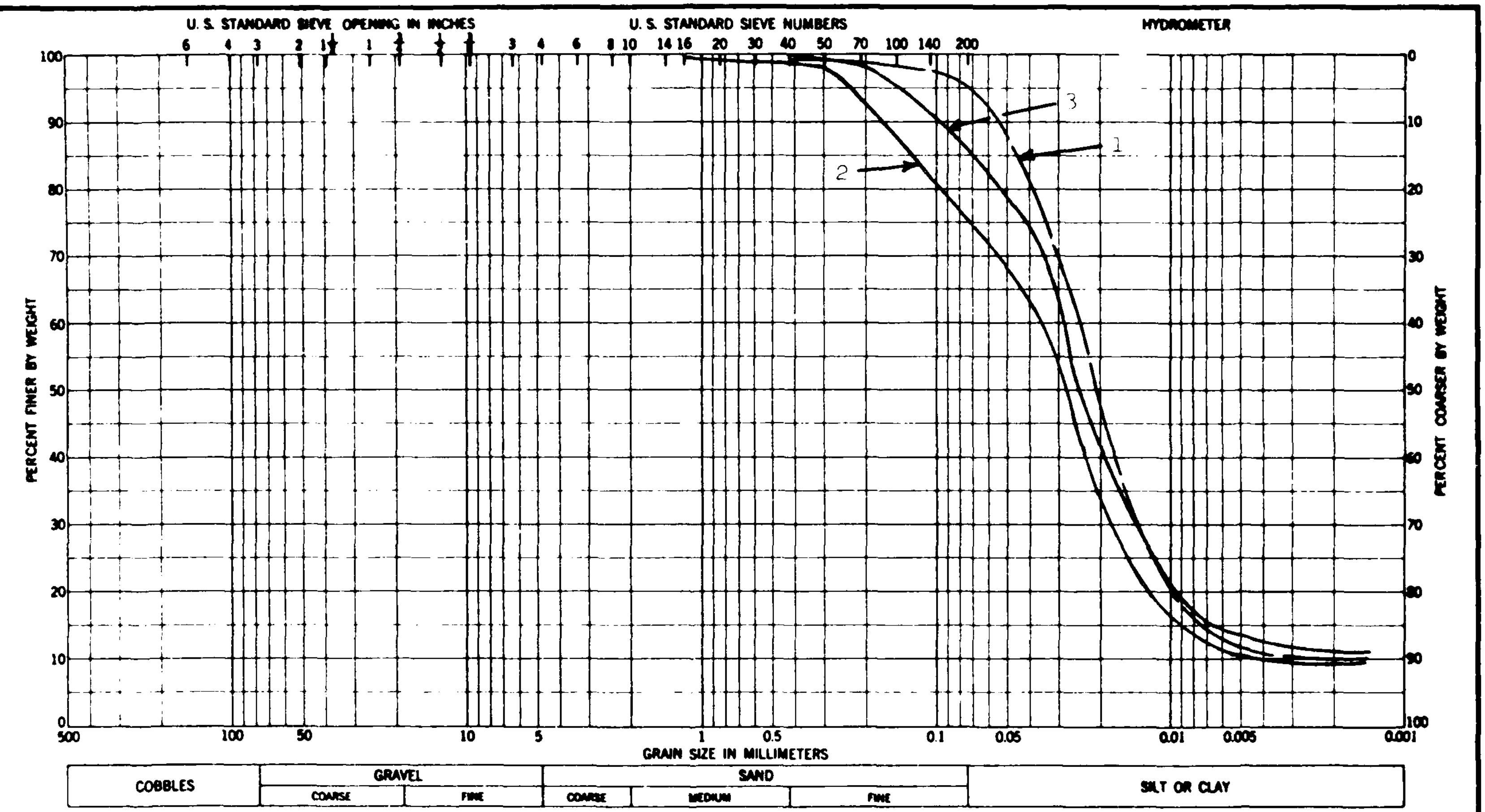
GRADATION CURVES

ENG FORM 1 MAY 63 2087



STREAMBANK EROSION STUDY
CROSS SECTIONS
DURDEN CREEK

PLATE 8



Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI
	Top Bank (TB)	Clay (CL)		31	22	9
	20' from TB	Sandy Clay (CL)		28	20	8
	40' from TB	Sandy Clay (CL)		31	20	9

Project Streambank Erosion Study

Area Big Black River

Boring No.

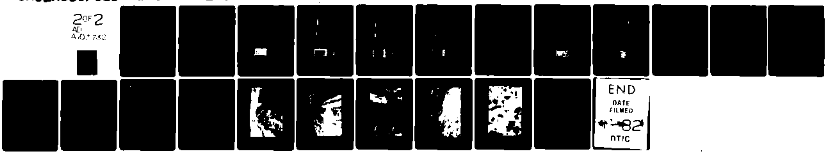
Date

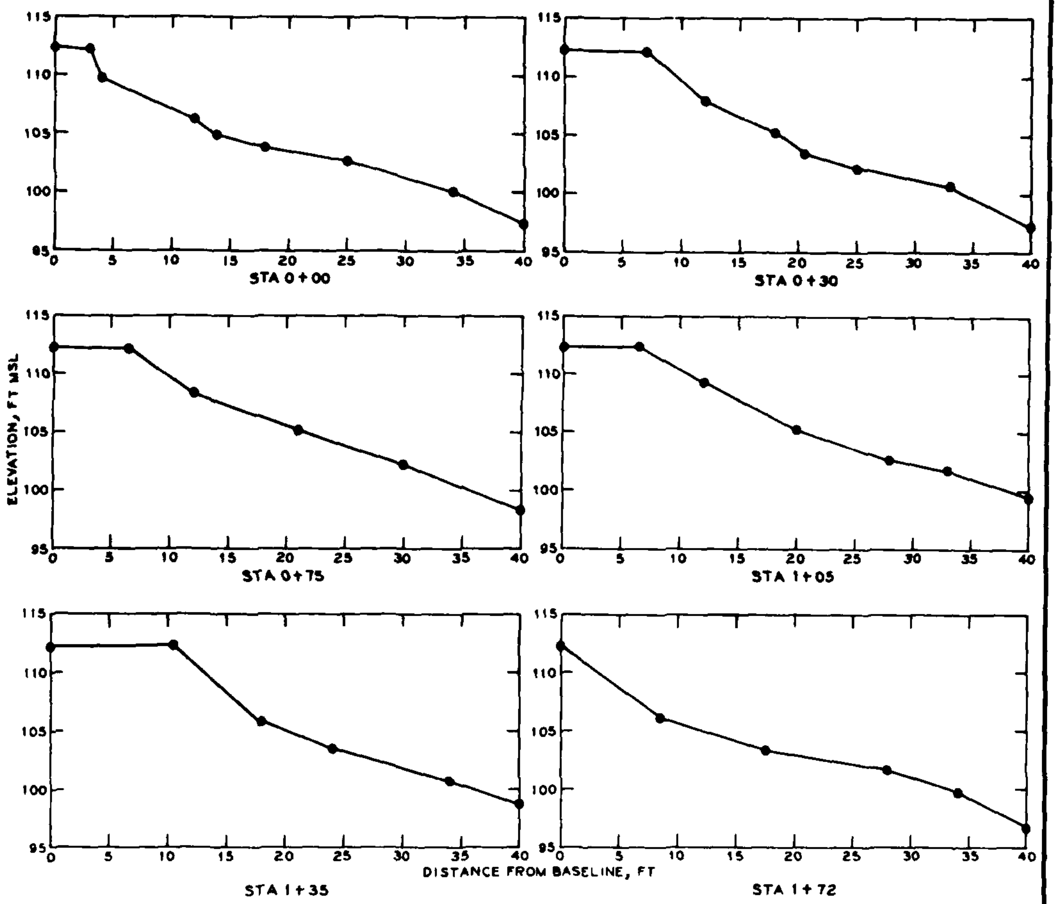
GRADATION CURVES

ENG FORM MAY 63 2087

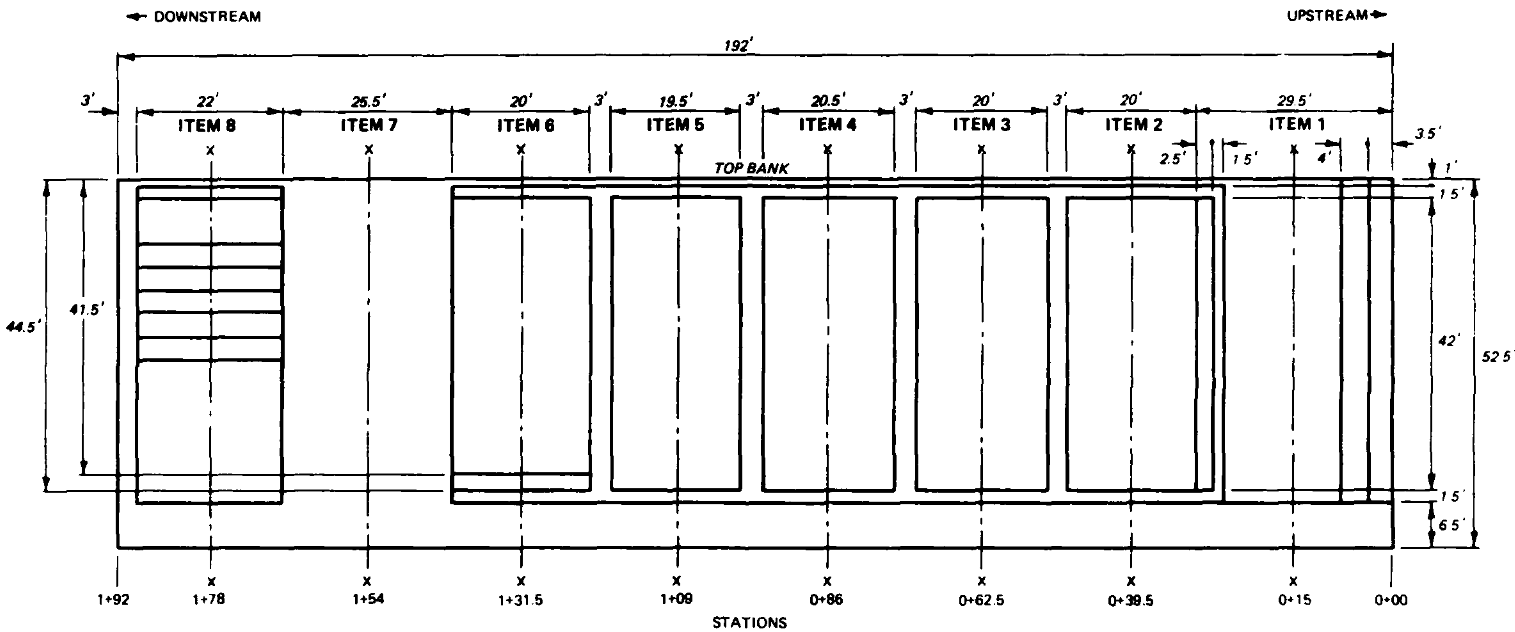
AD-A107 732 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 13/2
EVALUATION OF MEMBRANE-TYPE MATERIALS FOR STREAMBANK EROSION PR--ETC(U)
AUG 81 D W WHITE
UNCLASSIFIED WES/MP/GL-81-4 NL

2 OF 2
AD
A107 732





STREAMBANK EROSION STUDY
BANK CROSS SECTIONS
PRIOR TO CONSTRUCTION
BIG BLACK RIVER



PLAN

LEGEND

ITEM 1 RIPRAP ON BIDIM C-38 FABRIC–(SEE SHEET 2)
TIE-IN TO TEST ITEMS
ITEM 2 HYPALON 5x5 MEMBRANE–(SEE SHEET 3)
ITEM 3 HYPALON 10x10 MEMBRANE–(SEE SHEET 4)
ITEM 4 T-15 MEMBRANE–(SEE SHEET 4)
ITEM 5 T-16 MEMBRANE–(SEE SHEET 4)
ITEM 6 T-15 MEMBRANE MESL–(SEE SHEET 5)
ITEM 7 RIPRAP ON BIDIM C-38 FABRIC–(SEE SHEET 7)
ITEM 8 STEPPED T 15 MEMBRANE MESL–(SEE SHEET 8)

X–·–X CROSS-SECTION DATA POINTS

NOTE NO SCALE ON ANY OF THE SHEETS

STREAMBANK EROSION STUDY
BIG BLACK RIVER
TEST SECTION LAYOUT

PLATE 11 (SHEET 1 OF 9)

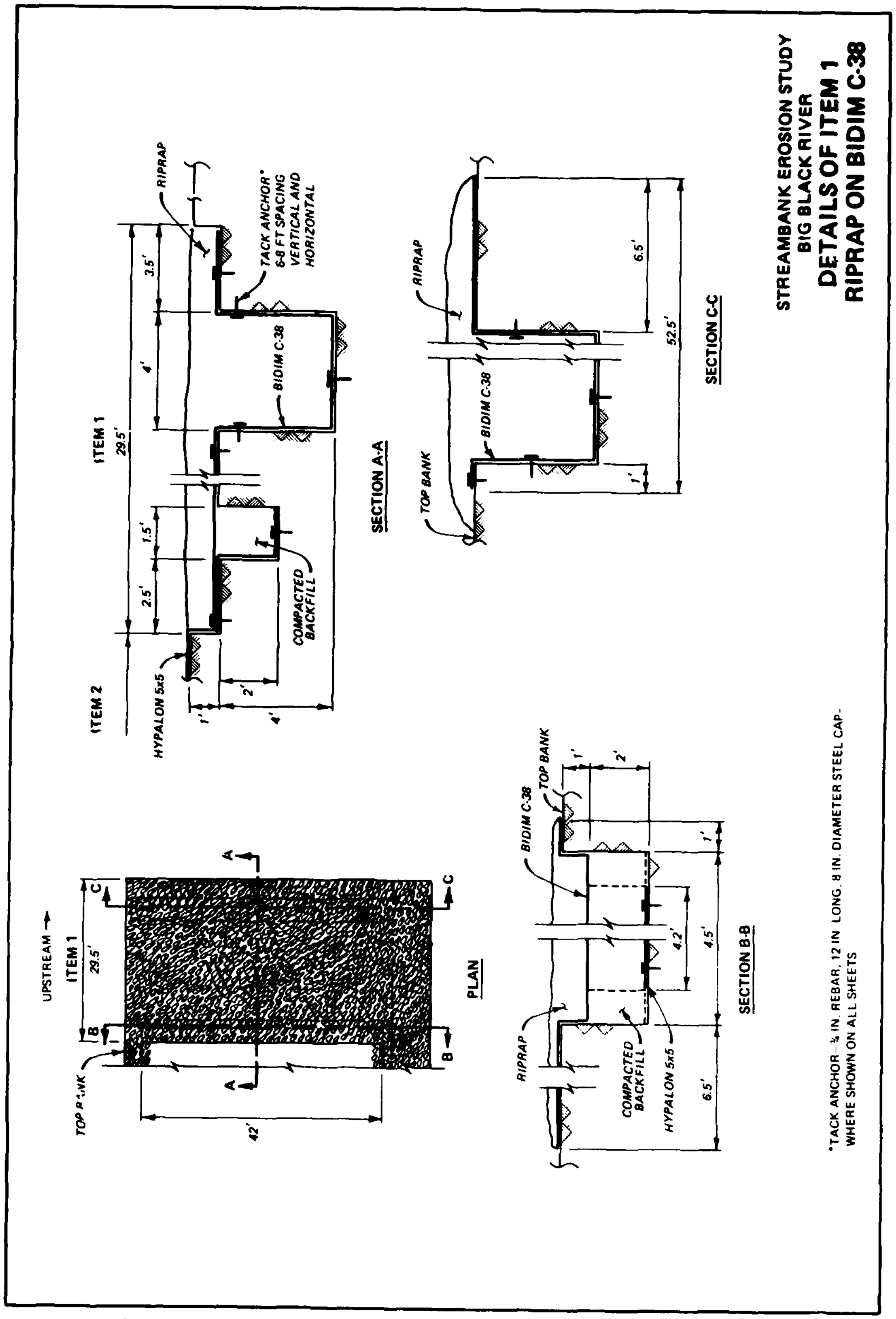


PLATE 11 (SHEET 2 OF 9)

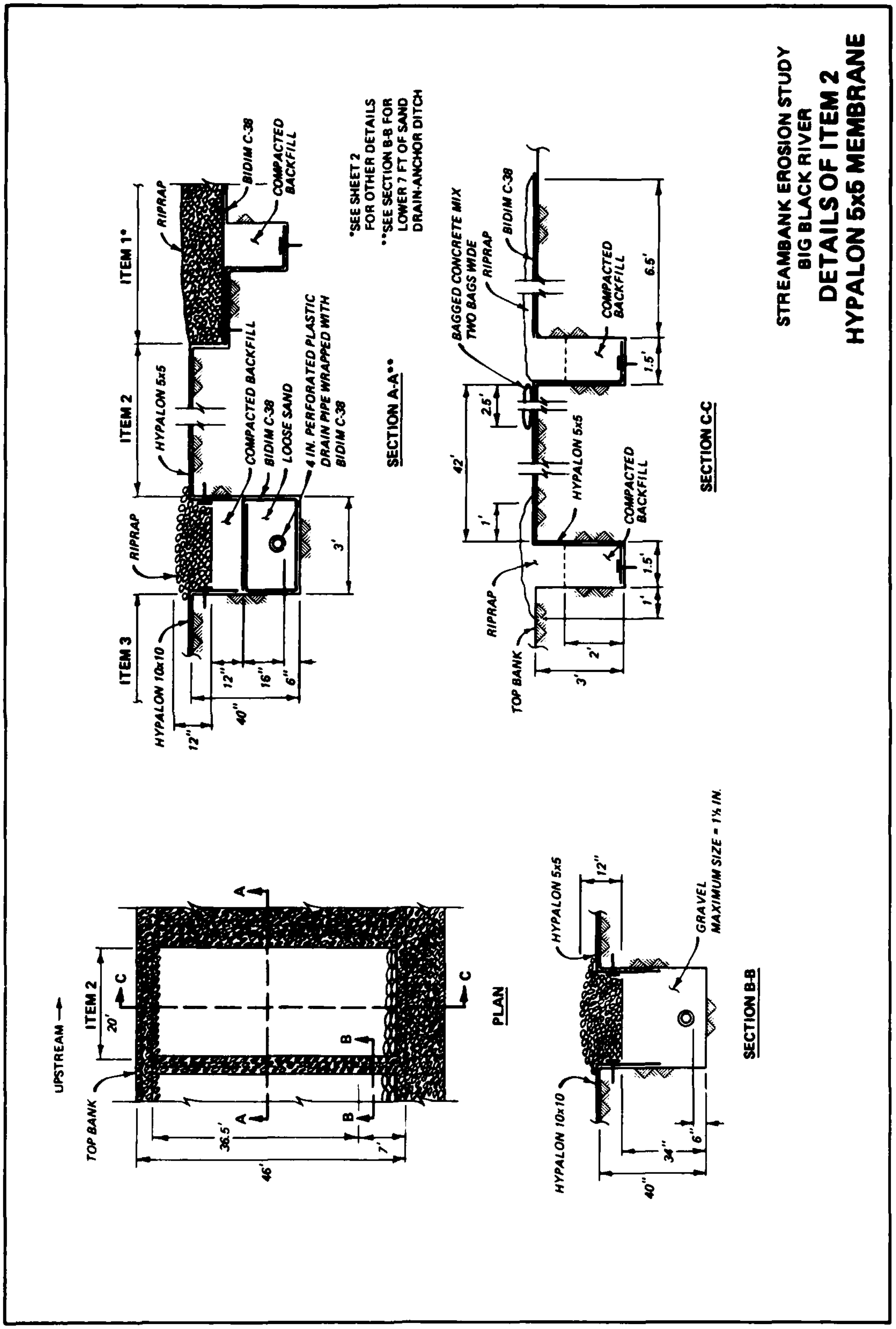
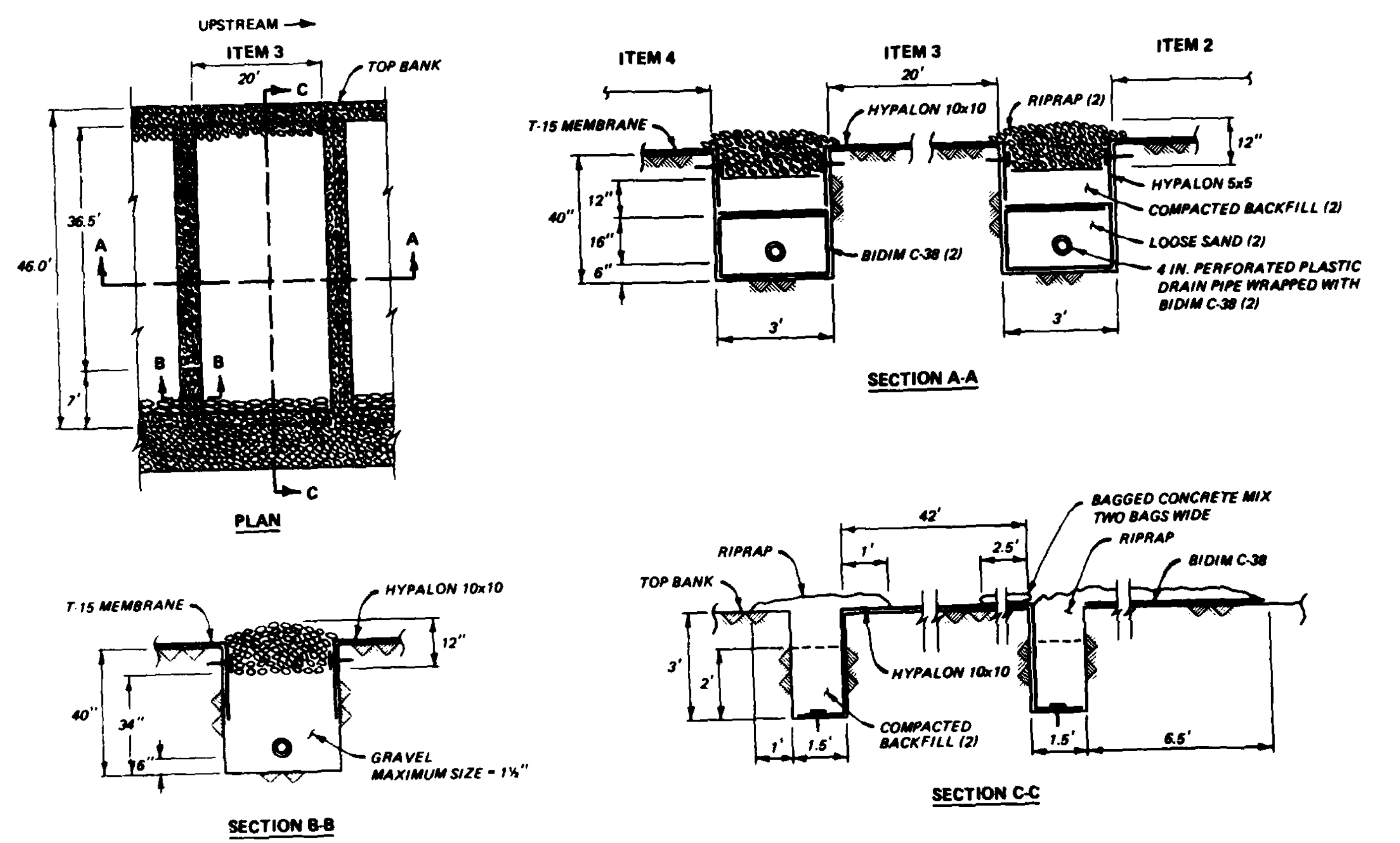


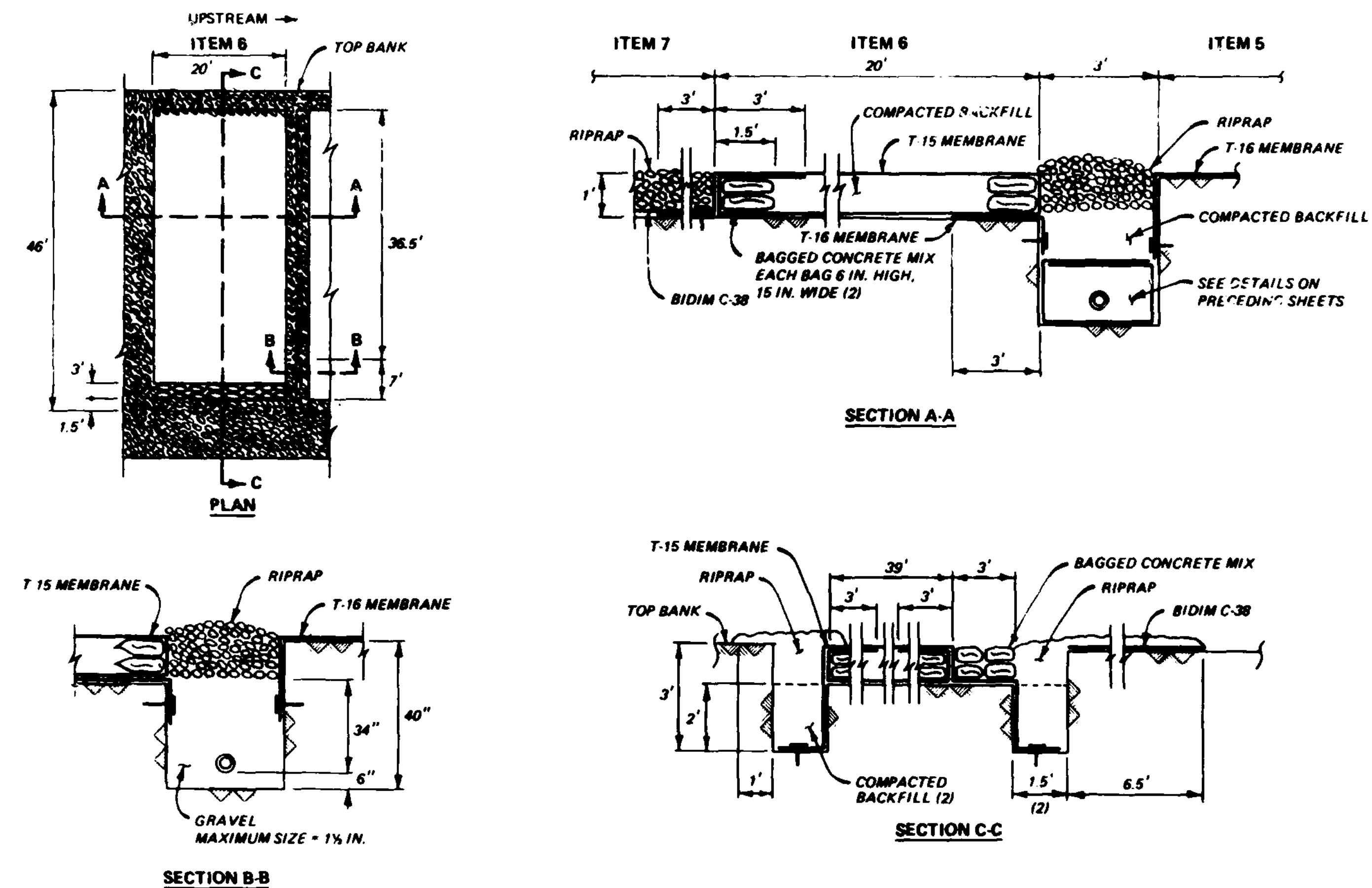
PLATE 11 (SHEET 3 OF 9)



*DETAILS OF ITEMS 4 AND 5--SAME AS FOR ITEM 3 ABOVE EXCEPT WIDTH OF ITEM 4 IS 20.5 FT AND ITEM 5 IS 19.5 FT. MATERIAL ON ITEM 4 IS T-15 MEMBRANE AND ITEM 5 IS T-16 MEMBRANE.

STREAMBANK EROSION STUDY
BIG BLACK RIVER
DETAILS OF ITEMS 3, 4*, AND 5*

PLATE 11 (SHEET 4 OF 9)



STREAMBANK EROSION STUDY
BIG BLACK RIVER
DETAILS OF ITEM 6
T-15 MEMBRANE MESL

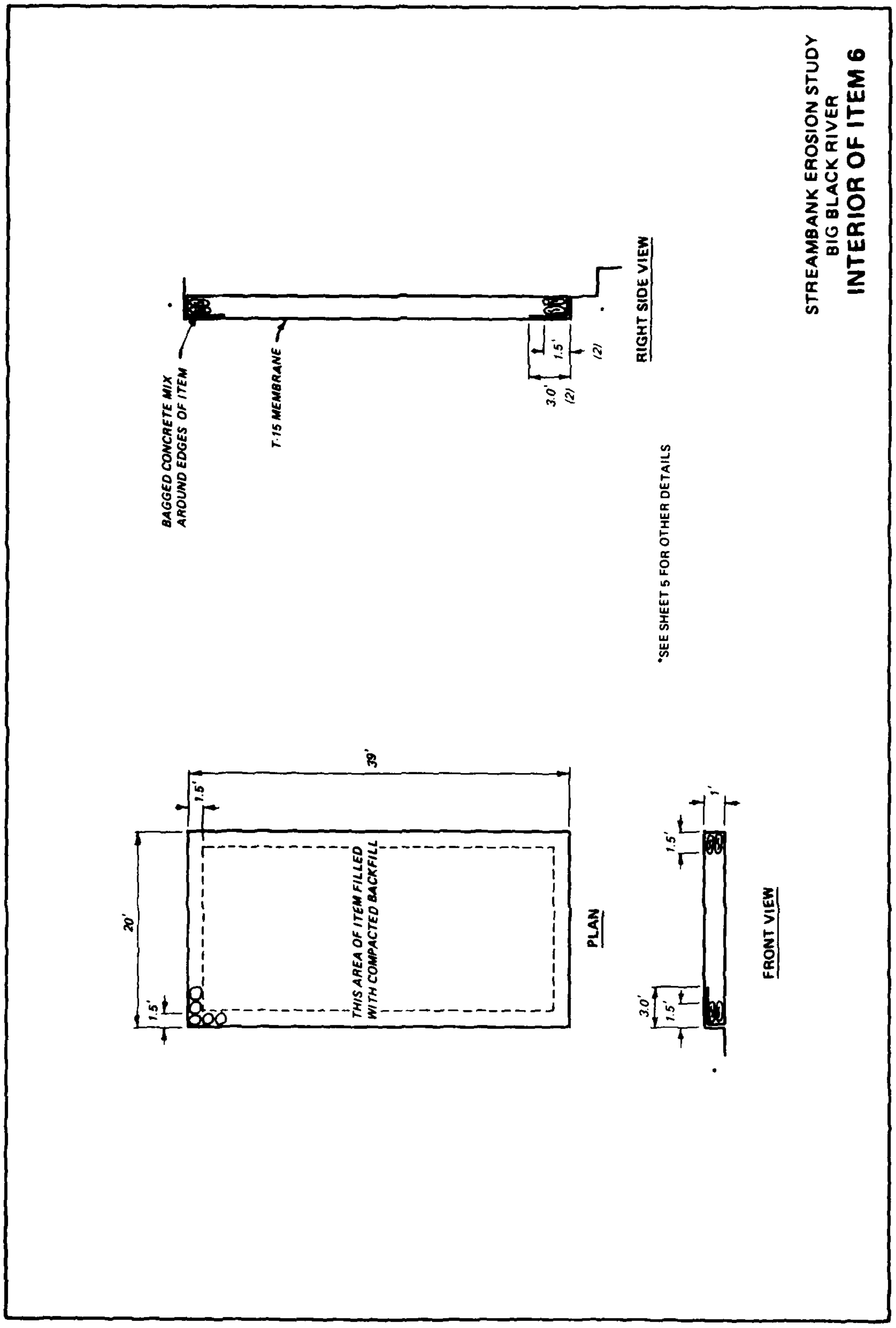


PLATE 11 (SHEET 6 OF 9)

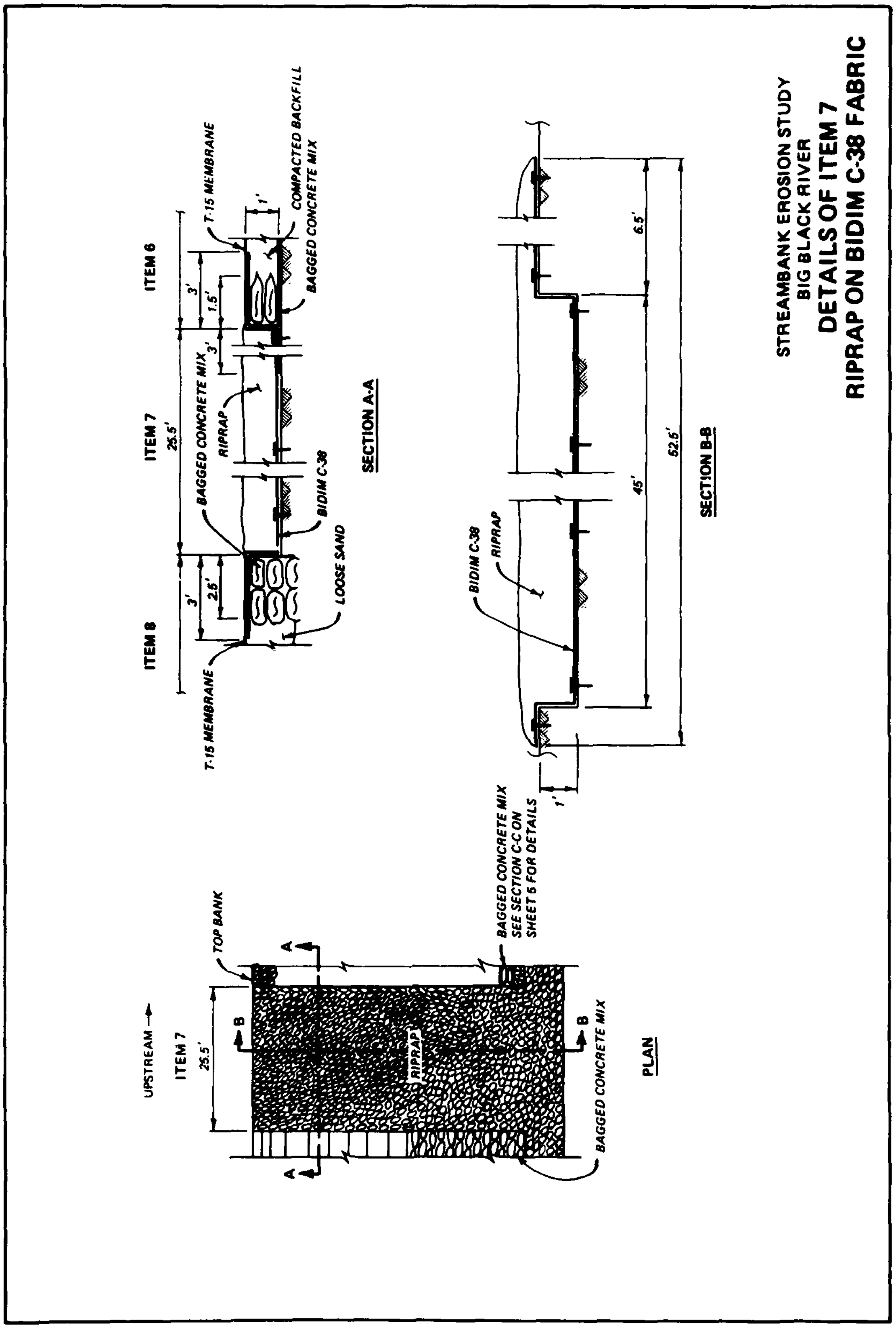
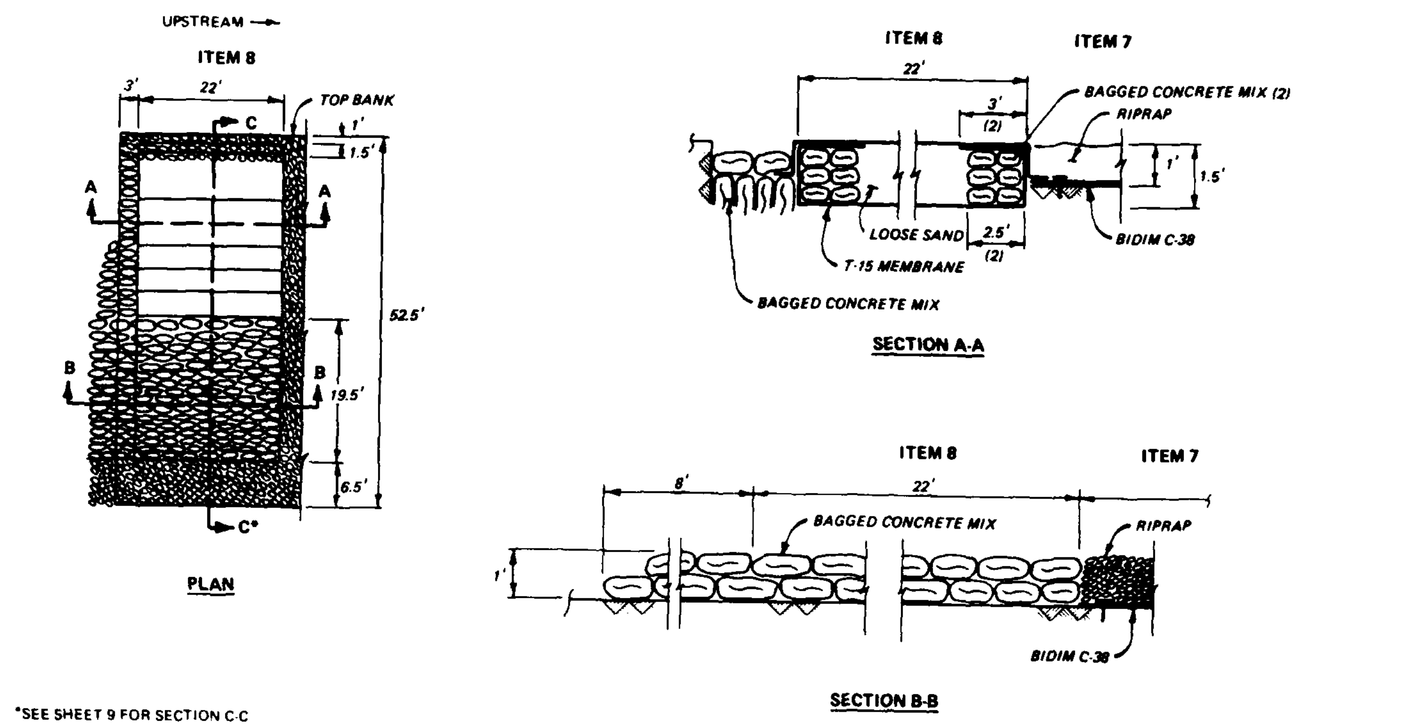


PLATE 11 (SHEET 7 OF 9)



STREAMBANK EROSION STUDY
BIG BLACK RIVER
DETAILS OF ITEM 8
STEPPED T-15 MEMBRANE MESL

PLATE 11 (SHEET 8 OF 9)

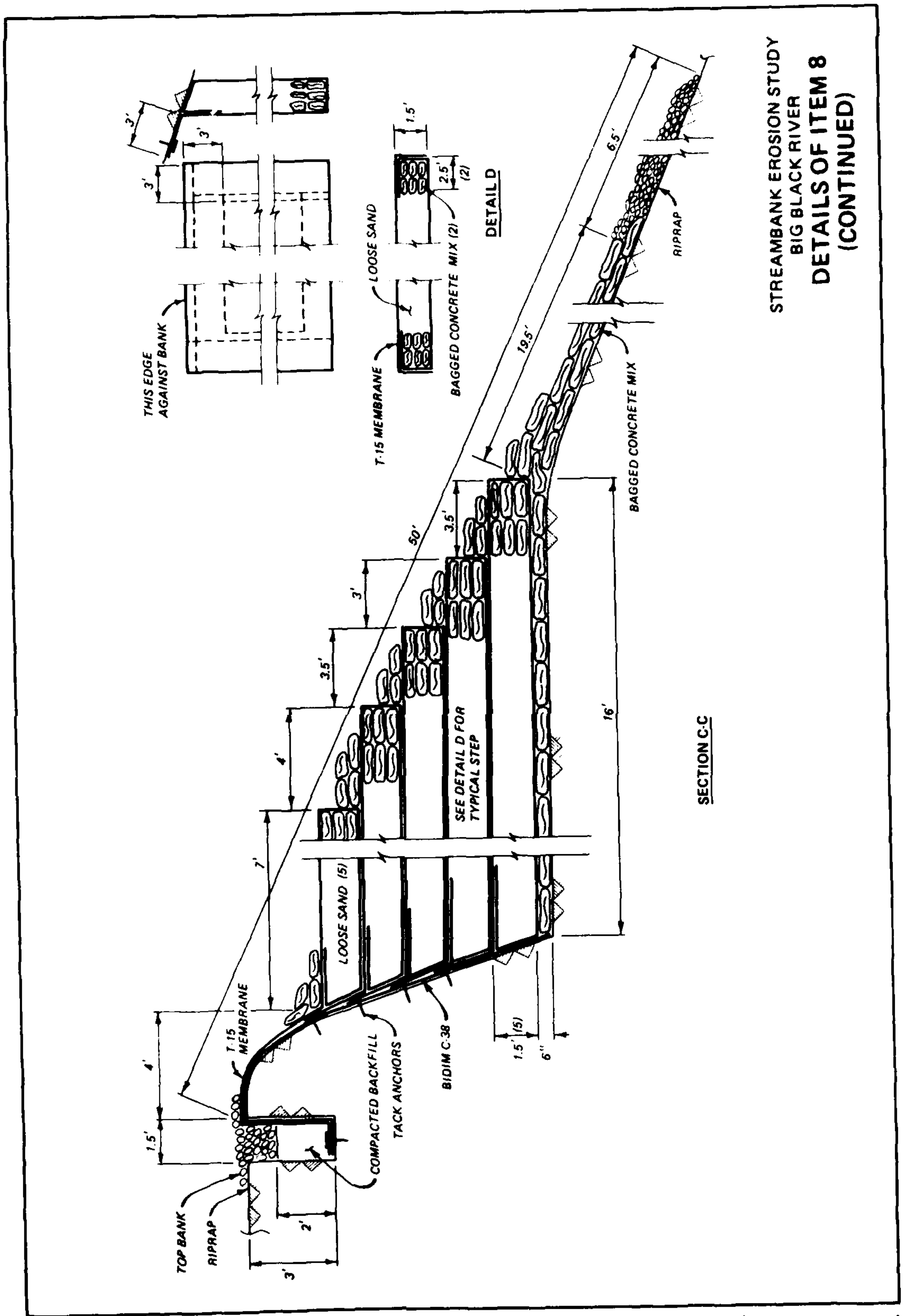
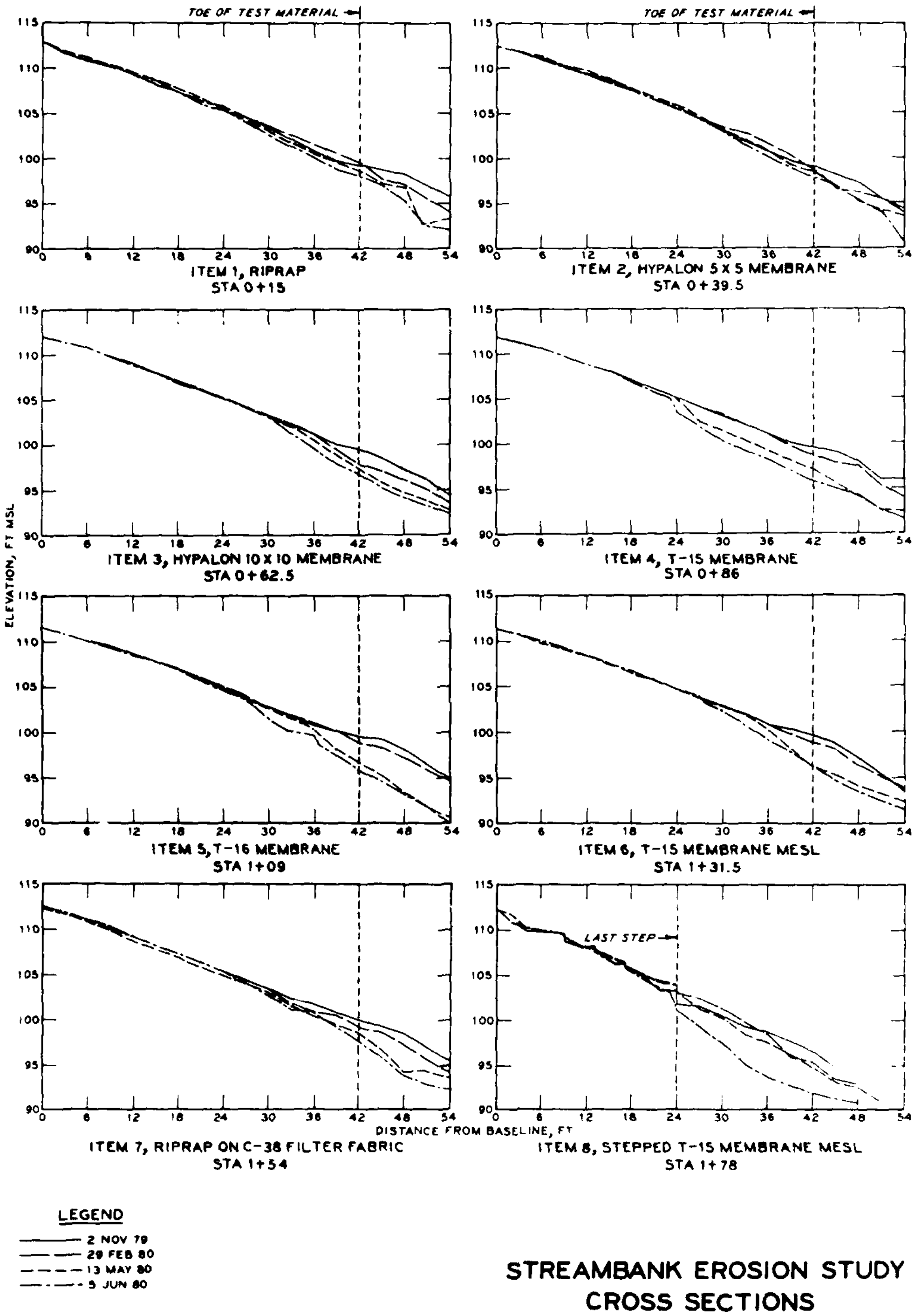
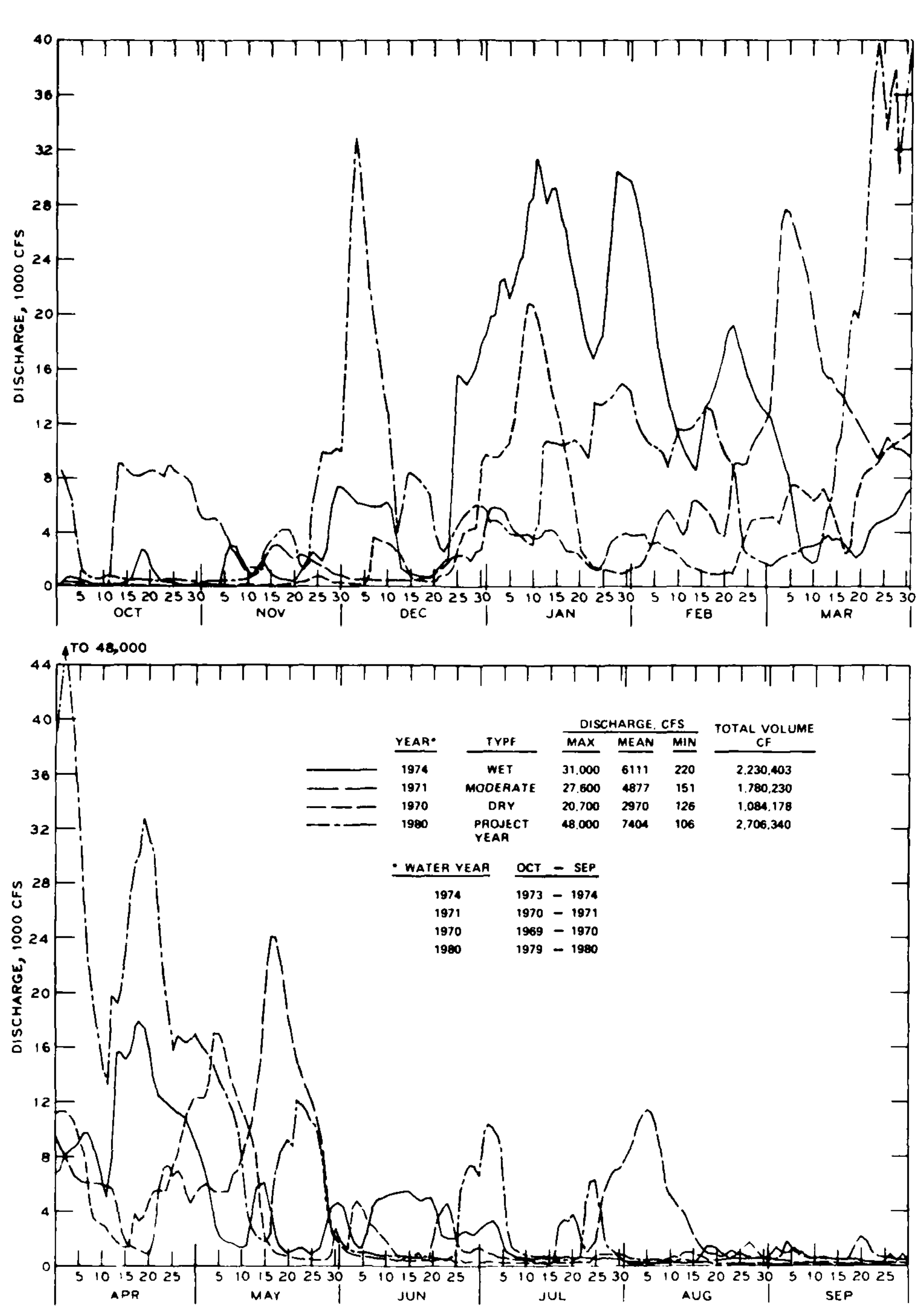


PLATE 11 (SHEET 9 OF 9)



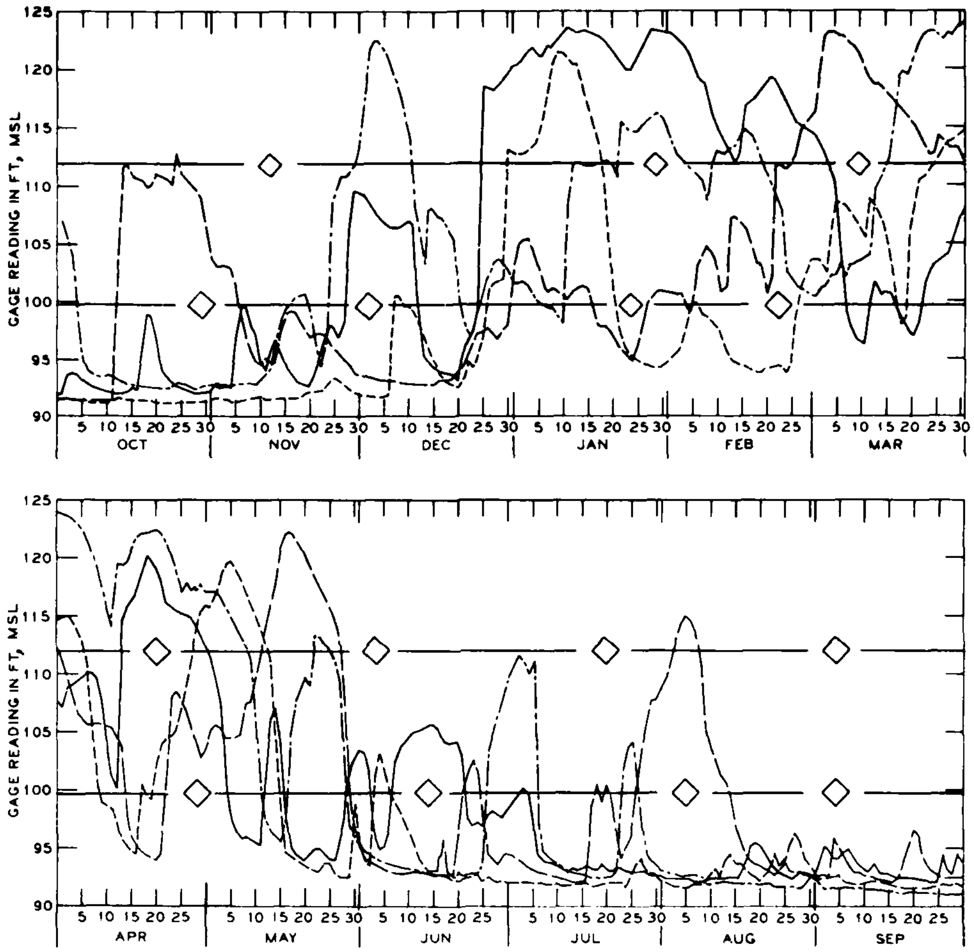
STREAMBANK EROSION STUDY
CROSS SECTIONS
BIG BLACK RIVER

PLATE 12



BIG BLACK RIVER DISCHARGE

BOVINA GAGE



	YEAR*	TYPE	GAGE READING IN FT, MSL MAX	MEAN	MIN
——	1974	WET	123.53	102.54	91.93
— —	1971	MODERATE	123.13	101.54	91.53
– – –	1970	DRY	121.33	97.79	91.43
–·–·–	1980	PROJECT YEAR	123.86	102.56	91.36

—◇— UPPER AND LOWER LIMITS OF TEST ITEMS

* WATER YEAR	OCT – SEP
1974	1973 – 1974
1971	1970 – 1971
1970	1969 – 1970
1980	1979 – 1980

BIG BLACK RIVER STAGE

BOVINA GAGE

PLATE 14

APPENDIX A: MEMORANDUM FOR RECORD - REHABILITATION WORK ON STREAMBANK EROSION PLOT AT BIG BLACK RIVER SITE

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
P. O. BOX 631
VICKSBURG, MISSISSIPPI 39180

IN REPLY REFER TO:
WESGP

10 February 1981

MEMORANDUM FOR RECORD

SUBJECT: Rehabilitation Work on Streambank Erosion Plot at Big Black River Site

Background

1. Eight test items had been installed on the slope of the bank of the Big Black River in October - November 1979. These items included one tie in riprap item, four membrane blanket items, one membrane-encapsulated soil layer (MESL), one stepped MESL, and one riprap item as the standard of comparison. Between late spring and early summer of 1980, the height of the water in the river fluctuated to such an extent that the bank along the river was saturated and the lower half of the test items slid and sloughed. This occurred not only at the test site but up and down the river. Funds were received in January 1981 for rehabilitation and reestablishment of vegetation (trees, etc.) on the slope of the bank in the area of the test items.

2. A view of the test area prior to rehabilitation work on 27 January in shown in Incl 1. This work involved setting out approximately 185 cottonwood and willow tree sprigs along the top (row 1) and along the slope of the upper bank (rows 2 and 3). Inclosure 2 shows a general view of the test area after planting of the sprigs. The sprigs which are approximately 3/4 to 1-1/2 in. in diameter and approximately 36 in. long were placed in the soil to a depth of 10 to 15 in. The sprigs were set out in three rows, each row having a staggered pattern with individual sprigs 30 to 36 in. apart as shown in Incl 3. The top row (row 1) consisted of a double row of both cottonwood and willow along items 5 through 7 (Incl 4). Willow sprigs were used along the top and lower bank of the other items.

3. The sprigs were set out by first punching a hole with a sharpshooter, then the sprigs were placed in the holes and the soil was backpacked around the sprigs. In the membrane items, a small slit was first made in the membrane with a sharp tool and then the sprigs were planted as mentioned above.

4. No sprigs were set out in the riprap areas since many small cottonwood sprouts were growing among the rocks (Incl 5). These had come up

WESGP 10 February 1981
SUBJECT: Rehabilitation Work on Streambank Erosion Plot at
Big Black River Site

as a result of seed being deposited along with silt during high water. These new sprouts measured 6 to 15 in. high with several being as high as 5 ft.

5. Photographs were taken before and after planting of the sprigs. The test plot will be monitored at regular intervals and various photographs and data will be recorded.

Dave A Ellison

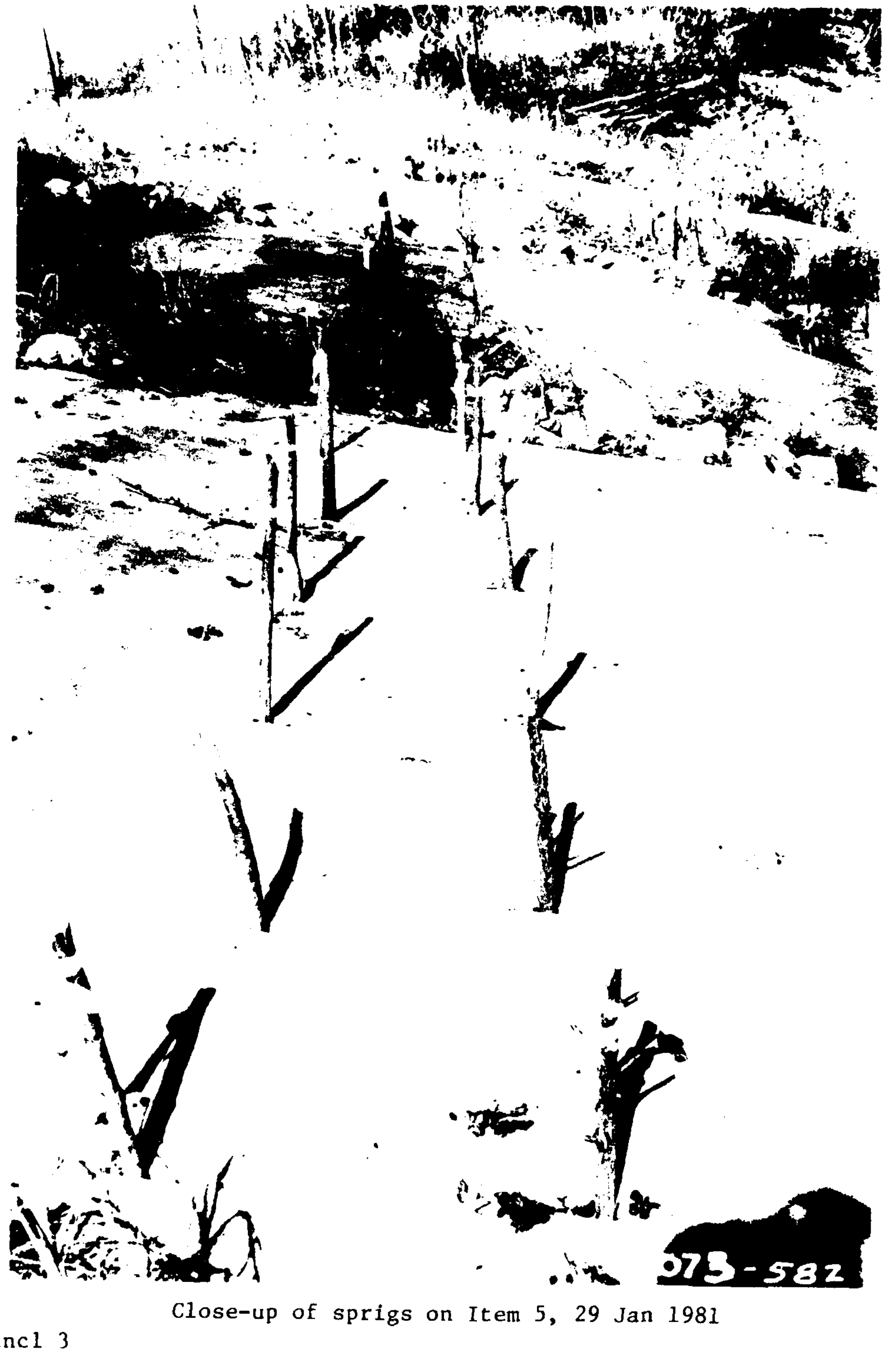
DAVE A. ELLISON
Engineering Technician
Pavement Systems Division
Geotechnical Laboratory

5 Incl
as

View (looking upriver) of test area prior to planting the sprigs, 27 Jan 1981

Incl 1

View (looking upriver) [illegible] test [illegible] after the sprigs were planted, 29 Jan 1981



Close-up of sprigs on Item 5, 29 Jan 1981

Incl 3

View (looking upriver) from top bank of test area after the sprigs were planted, 29 Jan 1981

Incl 4

Close-up of volunteer cottonwood sprouts between pieces of riprap, 29 Jan 1981

Incl 5

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

White, Dewey W., Jr.
Evaluation of membrane-type materials for streambank erosion protection : final report / by Dewey W. White, Jr. (Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, [1981].
83 p. in various pagings, 28 p. of plates : ill. ; 27 cm. -- (Miscellaneous paper / U.S. Army Engineer Waterways Experiment Station ; GL-81-4)
Cover title.
"August 1981."
"Prepared for Office, Chief of Engineers, U.S. Army under Work Unit 4, Section 32, Streambank Erosion Control, Evaluation and Demonstration, Act of 1974 (PL 93-251)."

1. Embankments. 2. Erosion. 3. Membranes (Technology). 4. Soil conservation. I. United States. Army. Corps of Engineers. Office of the Chief of Engineers. II. U.S. Army Engineer Waterways Experiment Station. Geotechnical

White, Dewey W., Jr.
Evaluation of membrane-type materials for : ... 1981.
(Card 2)

Laboratory. III. Title IV. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; GL-81-4.
TA7.W34m no.GL-81-4

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